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Knowledge Sharing Strategies for Large Complex Building Projects

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Bana sonsuz destek olan anneme,
babama ve biricik abime...

1 Introduction

Every Turkish architecture student has been told the legend about the Süleymaniye mosque. The mosque, built in 1558, is the work of Mimar Sinan, the well-known Ottoman architect who completed 477 major works (Kuran 1986) that have lasted for generations. He used each new building as a tool to find more innovative techniques and applied these solutions in his subsequent work. This legend based on the appreciations which has been passed from student to student, recalls that some time ago, a group of experts were analysing the load-bearing arches of the Süleymaniye mosque legend this mosque is mentioned as when they found a hidden compartment in which a mysterious bottle had been placed. The bottle held a message from Mimar Sinan that read, 'If you find this message, the keystones are broken and most likely you do not know how to replace them'. The message continues by giving advice on how to replace the keystones. Although this is merely a legend and has never been confirmed, in different versions of this legend, the mosque refers to his 'apprenticeship' work, Şehzadebaşı mosque), the story is still shared among students as a reminder that they have to pay attention when archiving the design rationale. Irrespective of it being true or false, this story can be used to illustrate how difficult it is to understand these great works and share the knowledge of the actors who designed and built these works. This story exemplifies the power of knowledge sharing across generations by means of legend of Mimar Sinan's 'message in a bottle'. Of course, this was not why I decided to undertake this study, but the longing to understand the reasons why sharing knowledge is difficult has served as inspiration for this research project.

My motivation for this project starts with my own experience as a practitioner architect. During the five years of my work as a practitioner, I was involved in both middle and large-scale projects. The projects varied from stadiums, mixed-use centres, and five-star hotels to high-income housing estates. In each project, as a member of the design team, I was faced with the constant redundancies, and re-designs that occur because either the clients do not know exactly what they want, or the actors do not understand what the others are actually saying and what their needs are during the project. In both cases, the input that the actors provided during the design process was instrumental in re-shaping the design. Moreover, there was never just one single 're-shaping' process in these projects. There was often a significant level of misunderstanding among the actors, which resulted in an enormous number of e-mail messages with sketches and drawings attached, and subsequent phone calls. It was not the fact that they had to deal with more than one discipline, but I believe that each member of a design crew felt frustrated by the constant changes, information overloading, and processing that each actor actually wanted. As a designer in this particular setting and frustrated by these problems, I eventually learned to focus on understanding both the reasons and conditions that account for why actors in the design process have such little understanding of each other's practices and why actors continue to find themselves in the same difficult situation with each new project they embark on. The question I wanted to investigate was why, as part of a design team, I do not easily share my knowledge during the design process, and why I do not understand what others are trying to say in a project environment. That is how I ultimately became engaged in the field of knowledge and knowledge management.

In this study, I examine the current extent of knowledge sharing between actors who form design teams of Large Complex Building Projects (LCBPs), the problems that limited knowledge sharing causes in such projects. As part of this analysis I compare deliberately designed and emerging project-specific Knowledge Sharing Strategies (KSS). Based on this analysis, I propose an approach how to promote knowledge sharing in future LCBPs.

Understanding the current knowledge sharing processes employed by actors in large complex building projects forms therefore the core of this study. Hence, the dynamics that both hinder and promote actors' knowledge sharing processes within LCBPs are investigated. Before making this investigation, the natures of LCBPs are elaborated since these projects are 'the playgrounds' of the design team actors for knowledge sharing. In the end, this study makes three contributions:

1. an understanding of the nature of LCBPs (as the playground of actors) that serves as a basis for exploring potential barriers and current approaches towards knowledge sharing among design team actors,
2. the formation of an analytical framework that synthesizes aspects for knowledge sharing strategies and investigates the current strategies that are targeted at building knowledge sharing between actors which has been undertaken in regard to the proposed framework of KSS,
3. the practical implications that provide knowledge for practitioners so they can design and implement knowledge sharing strategies for LCBPs.

This introductory chapter provides the background information for this research study. It begins by identifying LCBPs as a field of study. The chapter explains why this study is necessary, what the research gap is, and how this research has been conducted. This chapter concludes with an outline of the dissertation. Below, I begin by clarifying LCBPS as our field of study.

§ 1.1 Large Scale Complex Building Projects

Since a building project can be characterized by huge complexity and the temporary involvement of many different participants within different fields of focus and interests (Taylor et al. 2006; Jensen et al. 2009), large complex building projects carry a higher level of complexity in particular due to their programs, collaboration forms, budget and required technical knowledge. In both the design and construction phases of LCBPs, a large number of organizations contribute to the projects with their domain knowledge in order to realize the technically and socially complex product, which integrates a multi-faceted knowledge. The field of this study is large complex building projects and the various design practices involved during the design process of large complex building projects Since current knowledge sharing processes of organizations in multi-disciplinary design process of LCBPs can be examined through real-life projects, selecting the cases was of great importance. In the pre-selection of the case studies, the criteria used to determine the LCBPs were treated as self-explanatory. Therefore, the perception of large complex building projects in this study has been further clarified. This clarification is meant to set a common ground for which these case studies have been selected.

Project number	Floor area (10.000 m2)	Budget (billion RMB)	Starting time	Completion time
1	9.2	1.32	August 1993	July 1997
2	5.1	0.53	December 1993	October 1997
3	30	4.75	January 1993	December 1998
4	7.1	1.05	February 1994	April 1999
5	23	2.4	January 1994	June 2000
6	10	1.4	April 1997	May 2000
7	14	0.9	July 1998	June 2000

Table 1
Seven examples of Large Complex Building Projects (Wang 2000)

In Wang's survey on LCBPs in China, he selected seven projects comprising their programmes (min. 51,000 m2 to max. 300,000 m2), the budget (min. 65m euros – converted from 530RMB to 600m euros – converted from 4.75 Billion RMB) by using the eighty-eight storey Jin Mao Building in Shanghai as an example. Based on his research, in the 'smallest' projects design development phase lasted four years. Nevertheless, his selection refers to only high-rise buildings, which have been designed by foreign architectural bureaus with local partners. In addition, he does not discuss the complexity of the projects regarding their functions and programs, but refers only to their size (see Table 1).

Jensen et al. (2009) in contrast, suggest a new university building project in Kolding as an example for analysing large complex building projects. Yet, the perception of large complex building projects remains implicit. Swyngedouw et al. (2002)conducted a research study on large complex building projects within an urban development context. They provide examples such as museums, waterfronts, exhibition halls and parks, business centres, and international landmark events, as the vehicles for urban policies. Their example projects include Kop van Zuid in Rotterdam, the Olympic City in Athens, the Southbank in London, and the Guggenheim Museum in Bilbao. However, the criteria for 'largeness' of the example projects remain ambiguous. Other scholars, such as Floricel et al. (2001), analysed large engineering projects such as power plants, highways, bridges, tunnels, and airports. They draw attention to their life span, the unpredictable nature of their engineering process and they claim that traditional planning approaches become invalid in such projects, and propose that these projects carry a certain level of complexity due to their unpredictable nature. Nevertheless, Floricel et al. (2001) do not make a clear distinction between what comprises the complexity of projects and what causes unpredictability in the project processes.

Jones et al. (2008) classify four types of inter-organizational projects; single project organizing, multi-party organizing, network alliances and constellations. He claims that network alliances and constellations serve as examples for large-scale projects in the architecture and construction industry. The temporariness ranges from 6 months to several years (Mintzberg et al. 1988) in which a wide range of professionals work together to create the finished product. These projects are complex due to the need for multiple organizations' involvement, and the constant interaction, which in turn lead to challenges in inter-organizational coordination (Jones et al. 2008). Recurring relations with the same partners is desired since the projects lasted from 18 months to several years, require an understanding of one another's contributions, and work styles. Other examples of 'constellations' are large-scale engineering and construction projects. In these projects, there is usually one single client who acts as a public agency in order to deal with a social challenge issue. This type of client hires a large engineering firm to manage the resulting design and construction effort. Jones et al. (2008) found that the internal dynamics of these projects are designed around engineering milestones within a contractual deadline, which may evolve over time and they also might have irreversible commitments. Large-scale well-established firms dominate these projects and they tend to have a repeated interaction with their clients.

In this research, LCBPs refer to the projects that require a great deal of collaboration between organizations. This need for collaboration is due to:

- a need for multi-disciplinary knowledge in order to fulfil the various aspects of the overall design,
- the complex structure of organizations involved on the client and design team side,
- a wider vision beyond the functional requirements (i.e. projects as development vehicles for organizations, areas.

Various examples of LCBPs can be seen in urban transport projects such as train stations where upper and underground structures are interfaced, airports, stadiums comprising various functions besides serving as a sport facility, etc.

§ 1.2 The Value of Knowledge Sharing in Large Complex Building Projects

Knowledge Sharing is of interest to various fields such as project management, knowledge management, organizational learning, and economics. In each field, the perception of knowledge is different. This distinction results in variety of approaches that deals with knowledge sharing.

In this study, knowledge is perceived as being both the individual assets that serve as well as the explicit and implicit dimensions. It is also a collective asset that resides also in communities and which is generated through social relationships (Wenger 1998; Maaninen-Olsson et al. 2008). Knowledge is often tacit, intangible, and context-dependent and it is articulated in the changing responsibilities, roles, attitudes, and values found in the work environment. In a project environment, knowledge enables individuals to solve problems, take decisions, and apply them to action. As a consequence of the decisions and action taken, knowledge (both individual and organizational) can be remodelled and primed for adding new knowledge during the project course. The accumulation of knowledge starts by generating knowledge from individuals who work within the design crews/teams, while creating their artefacts (i.e. drawings, sketches, calculations, and reports). Through these artefacts, individuals engage in design dialogues and externalize design solutions. These dialogues occur both verbally and non-verbally. Thus, knowledge is generated by individuals, shared between individuals or groups, integrated in the projects, and preserved within organizations during these processes. In this study, the process starting from individuals, sharing knowledge among actors and being integrated in the design process is called 'Knowledge Sharing'.

In large complex building projects, knowledge sharing is crucial among design team actors. In these projects, design –per definition – represents a process in which actors solve a complex problem and an outcome that requires multi-disciplinary knowledge to solve the problem. In this process of achieving the outcome, many organizations provide their disciplinary knowledge. Various organizations are appointed due to their domain knowledge that results in their final artefacts. The appointment of these organizations requires that the main design task be divided into disciplinary tasks. Therefore, LCBPs have a great division of labour. These organizations are appointed to conduct parallel design processes and to deliver their artefacts to the clients and to each other in order to integrate the sub-solutions. This signifies that organizations have several design processes, in which a constant exchange of artefacts and interactions takes place. Here, a synchronization of various design processes emerges in which organizations are expected to collaborate. In solving the main task synchronously, organizations exchange their artefacts in which their domain knowledge is embedded, they interact and share their insights while complementing the exchanged artefacts. This exchange, both social and physical, externalizes the discrepancies in ways of producing artefacts and approaching the problems, and therefore differences can be seen amongst the actors working within the design team. In each new large complex building project, there are differences in the design team regarding different approaches, design methodologies, and the perspectives taken towards the design task.

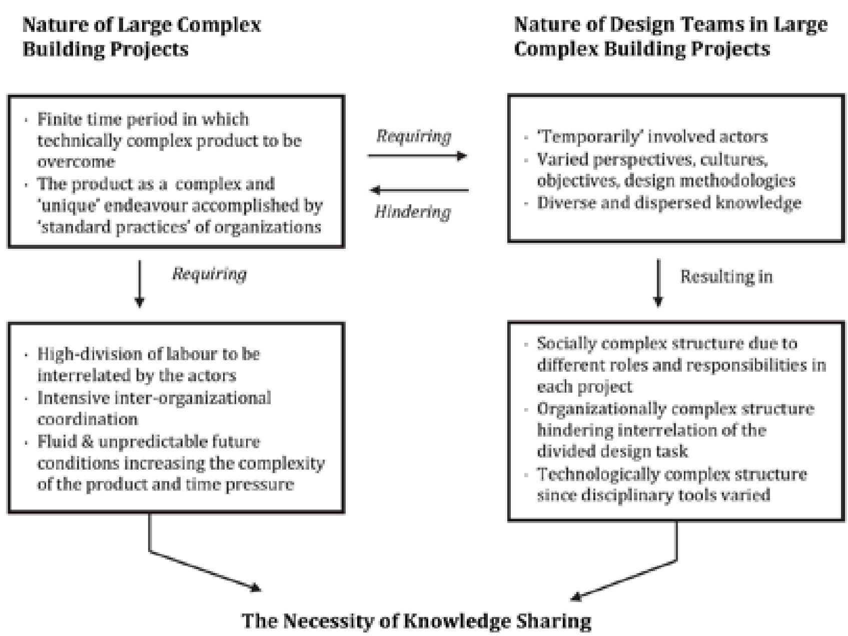

Figure 1
The characteristics of large complex building projects and their design teams which challenges and requires knowledge sharing (© Bektaş)

Figure 1 illustrates the interrelation between large complex building projects and their design teams that are working on these projects. The figure illustrates how unique and complex design problems are handled by a design team, which consists of actors temporarily grouped together. These actors represent their domain knowledge and have their diverse work methodologies, perspectives, and cultures. This diversity and temporariness of projects challenges knowledge sharing among actors and hinders them from finding solutions to the main design problem within the initially planned time and money. The reason behind problematic knowledge sharing comes from the interrelationship between diverse nature of the design team and the project. Finding a solution for the main design problem requires a high-division of labour and its interrelated aspects. This also requires intensive coordination among the various organizations, which form the design team and which work on the design problem. The design team organizations work on changing conditions over time and deal with the complex sociality within the team as well as dealing with the complex design problem. A socially, organizationally, and technologically complex design team works on a complex design problem. In order to work within the time agreed upon and the budgetary costs, design team organizations need knowledge sharing.

§ 1.3 Problems of Knowledge Sharing in Large Complex Building Projects

The problem examined in this study is two-fold:

1. Knowledge sharing among actors in the design process of large complex building projects is limited and hence there is not much shared understanding within the design team of these projects. There are constraints that limit the shared understanding within the design team in achieving their project objectives.
2. Managers are not sufficiently aware of the importance of knowledge sharing (particularly regarding the social process of knowledge sharing). This lack of awareness results in a lack of deliberately planned and implemented knowledge sharing strategies that promote inter-organizational knowledge sharing processes for large complex building projects.

Below, these two problems are identified and interlinked.

As stated in Section § 1.2, large complex building projects represent a temporary period in which a complex and unique design problem can be solved by a socially diverse, technologically, and physically dispersed design team. While solving the complex and unique problem, actors engage in a 'virtual teamwork'. Due to their diverse disciplinary and organizational cultures, actors possess diverse perspectives in projects (Sole et al. 2000) with different focuses and interests (Taylor et al. 2006; Jensen et al. 2009). They have interdependency across their functional boundaries (Ayas 1997) and they have mixed goals and objectives organizationally (Turner et al. 1987), while realizing their unique and meaningful attempt (Jones et al. 2008) as "to do something that has not been done that way before" (Smith 1985) within a time schedule and a budgetary target (Turner et al. 2003). In this endeavour, the actors require intensive coordination so that they can deal with their interdependent design activities (Jin et al. 1996). During this period of coordination, actors need continual interaction that fosters the knowledge sharing among team members (Tsui 2006). Continual interaction builds relationships and provides channels for processing information (Tsai 2003). This interaction therefore creates a social infrastructure. Through this infrastructure, actors gather meanings embedded in the exchanged objects, and "interpretive barriers" between actors are reduced through team members engaging in highly interactive and iterative exchanges (Dougherty 1992). In this way, social interaction becomes important for the purpose of knowledge sharing.

However, building social interaction is not easy. The immediacy of project objectives and the finite life span of project activity mitigate the emergence of a social network of actors who are able to construct shared understandings (Bresnen et al. 2003). Besides, there is an absence of a shared work environment (consisting of the same colleagues, and on-going social interaction) in projects, and therefore actors lack mutual understanding (Alavi et al. 2002). They are challenged to incorporate new information into their understanding in order to solve the technical challenges that they face in projects (Fong 2003). Their temporal, spatial and cultural differentiation militate against sharing knowledge (Sole et al. 2000; Bresnen et al. 2003). This leads to broken feedback loops amongst actors and problematic knowledge sharing processes that result in a lack of shared understanding within the design team and constraining project objectives (Gann et al. 2000).

Since socially, technically and physically dispersed actors deal with complex and unique design tasks, and because they coordinate their interdependent processes in a finite time, knowledge sharing among actors in project settings becomes more complex and more problematic. However, little attention has been paid to dealing with knowledge sharing processes at the inter-organizational level, particularly for LCBPs. Moreover, there is a lack of emphasis on planned strategies that could enhance the social interaction of actors, and thus promote knowledge sharing within the design teams of LCBPs.

§ 1.4 Research Gap and Research Questions

As mentioned above in § 1.3, up until now, little attention has been paid to inter-organizational knowledge sharing processes in large complex building projects, and there is a lack of planned strategies for targeting inter-organizational knowledge sharing in large complex building projects.These two problems are interrelated. Nevertheless, there are several approaches that can be used to deal with these two problems. Some of these approaches utilize technology but they fail to target knowledge sharing at the project level. None of the approaches deals with deliberately designing and implementing inter-organizational knowledge sharing strategies for LCBPs. Also, there is no holistic framework which considers social interaction as a crucial pillar for designing and implementing inter-organizational knowledge sharing strategies in such projects. These issues combined define the research gap in this study.

The current approaches that deal with knowledge sharing focus mainly on the integration of design output such as codifying, rather than sharing knowledge (i.e. BIM (building information models), repositories). These approaches neglect the relevance of social interaction between people involved in projects. There are only implicit attempts to 1) ease the access to people's knowledge), 2) to promote interaction amongst people to externalize knowledge), 3) to validate interpretation of information exchanged between designers and should not be regarded as knowledge sharing strategies among actors. Therefore, the current approaches do not address a holistic approach. There is little evidence on inter-organizational knowledge sharing strategies in this holistic respect and little focus on the social interaction between design organizations, which is truly a crucial aspect of knowledge sharing in the realm of design and construction (see Wenger, 1998). A possible explanation for this could be that, due to the unique, temporary, and complex nature of such inter-organizational projects, it is not possible to design and implement a knowledge sharing strategy, as this would require inter-organizational commitment. However, in the context of large and complex building projects, cost overruns and delays are a most common and reoccurring problems. In a recent survey of major projects, nine out of ten had cost overrun, cost overruns of 50 to 100 percent were common, and overruns above 100 percent were not uncommon (Flyvbjerg et al. 2011, p.321). Therefore, a strategy for promoting knowledge sharing processes between the design team members across organizations is necessary. These are the research questions of this study:

Research Question 1: What are the typical characteristics of large complex building projects and in what way do these present challenges for knowledge sharing?

Research Question 2: How are these challenges of large complex building projects currently addressed and are there certain knowledge sharing strategies for large complex building projects that can be identified?

Research Question 3: Based on the literature and these empirical findings, which recommendations can be made to improve knowledge sharing in large complex building projects?

§ 1.5 Research Approach

This research is a qualitative and interpretive work using a comparative analysis of two cases Understanding the nature of large complex building projects and current practices regarding knowledge sharing, exploring current approaches towards stimulating knowledge sharing for large complex building projects and describing potential knowledge sharing strategies are crucial in this study. Therefore, a multi-case study approach was selected in order to address the aspects of organisational culture (Klein et al. 1999), to describe human behaviour (Miles et al. 1999), to be explorative to deal with multi-disciplinary aspects, and to offer detailed descriptions (Creswell 2009).

Two cases were selected to serve as examples of large-scale complex building projects carried out in two European cities. The case studies have been conducted to examine the factors that inhibit or facilitate deliberate knowledge sharing strategies at the inter-organizational level. In previous research the selection criteria for large complex building projects have so far remained implicit (e.g. Wang (2000), Jensen et al. (2009), Swyngedouw et al. (2002), Jones et al. (2008)). In this study, LCBPs are defined as projects that require a great deal of collaboration between organizations due to their complex organizational structure, that need a wider vision beyond their functional requirements, thus requiring multi-disciplinary knowledge domains due to the aspects of the projects to be fulfilled. Attention is paid during the projects on which actors have to collaborate and share their knowledge to realize the desired end product. Relevant examples are urban transport projects such as stations where the upper and underground structures are interrelated, airports, and stadiums, which comprise various functions beyond serving solely as a sport facility.

A rich set of data was collected for each case by using a non-participant observation approach. The data set included interviews of design team actors, observation diaries, video recordings of meetings (held at disciplinary and multi-disciplinary levels), and official project documents. The research methods, case descriptions, and collected data are reported in Chapter 3. The generalizability of the results were.Based on the outcomes of the panel, recommendations for practice are provided in Chapter 6.

§ 1.6 Outline of the Thesis

This thesis consists of six chapters (see Figure 2). After this introduction, the theoretical foundation of this study is outlined in Chapter 2. The chapter starts with the fundamental discussions regarding knowledge. These discussions elaborate on the two main fields of knowledge as Knowledge Management and Organizational Learning. Chapter 2 moves forward to review knowledge management approaches in the realm of design and construction, namely the content and the relational perspective. The third section focuses on knowledge sharing strategies within the context of large complex building projects. Chapter 2 concludes with a theoretical framework for understanding knowledge sharing in large complex building projects based on the Activity Theory and Mintzberg's concept of strategies as deliberate or emerging.

Chapter 3 contains an overview of the research approach used for this study. It provides the reasoning for selecting a qualitative approach and the rationale for the comparative analysis of two cases, and for selecting two real-life projects as examples of large complex building projects for the cases. The data collection, the data analysis and cases are described.

Chapter 4 reports on the analysis of the two cases regarding the first research question, the characteristics of large complex building projects and in what way these present a challenge to knowledge sharing.

Chapter 5 reports the analysis regarding the second research question, namely current Knowledge Sharing Strategies in use. Based on the 'Knowledge Diamond' model introduced in Chapter 2, the results are presented in terms of four dimensions: physical settings, tools, procedures, and social practices directed at knowledge sharing. The model is then used to report the analysis of the cases in terms of current knowledge sharing strategies. Through a cross-case analysis, I compare both cases to identify commonalities and differences.

Chapter 6 first summarises the results obtained from the two cases and discusses the possible generalizations of these results based on the analysis given in Chapters 4 and 5. The generalizability of these findings is critically examined based on the responses from an expert workshop in which seven senior-level practitioners experienced in large complex building projects reflected on the generalizability of the results. This chapter subsequently makes recommendations for practitioners involved in large complex building projects for designing and implementing knowledge sharing strategies. The practical implications have been drawn by synthesising the feedback provided by the experts on our recommendations for the design practice and they include a strategic template for practitioners. The chapter concludes with a critical reflection and suggestions for further research.

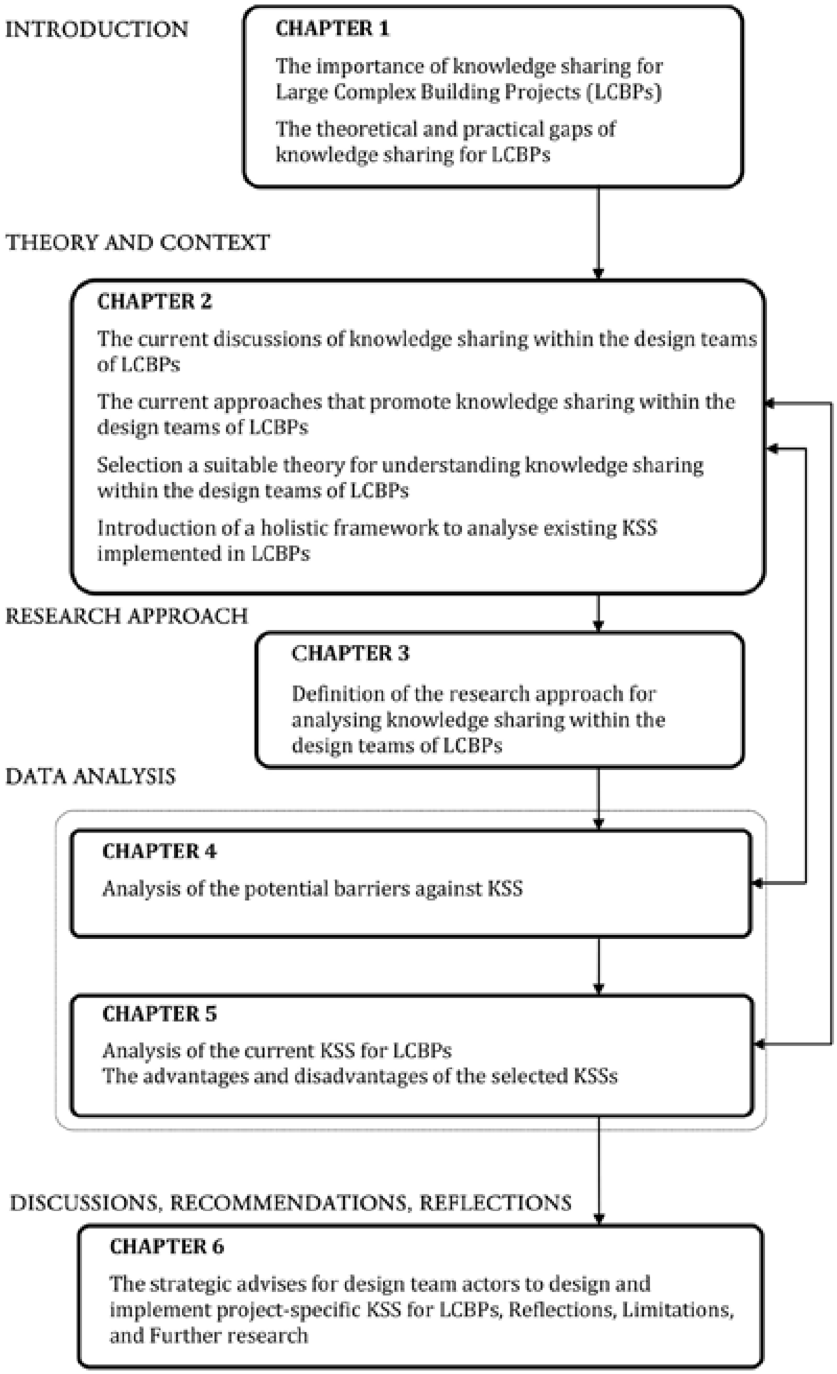

Figure 2
The outline of the thesis

2 Knowledge Sharing in Large Complex Building Projects

§ 2.1 Introduction

This chapter provides the theoretical background for this thesis. It comprises four sections. Firstly, this chapter reviews the concepts and dimensions of knowledge in the fields of Knowledge Management (KM) and Organizational Learning (OL). In this review, the concepts of data, information, and action are identified. In addition, the tacit and explicit dimensions are further explained. Secondly, this chapter explores management approaches for knowledge and identifies two perspectives on managing knowledge; 1) the object and 2) the community perspectives. Thirdly, it contextualizes knowledge and knowledge sharing in Large Complex Building Projects (LCBPs) by reviewing knowledge and exploring project-based management approaches. In this section, the core concepts of design knowledge are defined. This section concludes with key aspects of Knowledge Sharing Strategies (KSS) for LCBPs. Fourthly, this chapter proposes an analytical framework of KSS, the Knowledge Diamond, for LCBPs. The theoretical framework combines strategic concepts of Mintzberg et al. (1984) with concepts from Activity Theory about people's interactions in complex work settings. These sections address the following questions:

- What is knowledge in an organizational and inter-organizational context and how is knowledge shared in both contexts?
- What are the current perspectives on the management of knowledge?
- What are the current approaches that promote knowledge sharing within design teams of large complex building projects?
- What is a suitable framework for analysing knowledge sharing strategies for large complex building projects?

§ 2.2 Fundamental Discussions of Knowledge

According to many sources, knowledge management discussions originated in the early 1990s. The 'birth' of knowledge management is often referred to as Nonaka et al. (1995)'s book "The Knowledge Creating Company." They distinguish between tacit and explicit knowledge and they view it as part of a four-phased organizational learning model (including socialization, externalization, combination, and internalization). The concept of organizational learning was introduced in the early work of March et al. (1958). Both fields, Knowledge Management (KM) and Organizational Learning (OL) have addressed how organizations learn and manage knowledge.

Both fields have attempted to reveal different methods of managing knowledge in organizations. These methods endeavour to answer how an individual's knowledge can be captured, re-framed, and distilled into organizational processes. In Nonaka's model, four mechanisms are described that can be used for transferring the knowledge of knowledge workers (called investors by Stewart et al. (1998), Davenport (1999), Kelloway et al. (2000)), here interchangeably called as 'people' and/or 'actors') into organizational processes). These mechanisms are socialization, externalization, combination, and internalisation.

In organizational learning, actors represent the organizations to which they belong. The actors perform learning processes as they set, expect, and review the results achieved. It is a process of learning as presented in Bateson (1972)and then was taken up in organizational studies by Argyris et al. (1978) who introduced double-loop learning, which simply refers to the 'learning-after-learning' process. While learning refers to reviewing the actions (as detecting and correcting the errors), double-loop learning refers to reviewing the strategy chosen, the roles, and responsibilities and going beyond focusing solely on the actions. Double loop learning involves the process of change that occurs between individuals, teams, and organizations as they respond to their environment. The reaction may result in the change of method or in re-framing strategies.

As one of the first authors to write about knowledge management, Wiig (1993) claimed that KM can be approached by dividing it into four perspectives: the management practices perspective, the information technology perspective, the organizational efforts perspective and the development, supply and adoption rate perspective. Sanchez (2005) distinguishes KM approaches into two approaches: 1) personal approach – focusing on tacit knowledge and 2) organizational approach – focusing on explicit knowledge. Both approaches deal with the transfer of individual knowledge as a contribution to organizational knowledge (Sanchez 2005). Easterby-Smith et al. (2005) distinguish between the theoretical concept of OL and the practical side of KM on the one hand and content and process aspect on the other hand (see Figure 3). Senge (1997, p.1) defines learning organization as “where people continuously expand their capacity to create results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together”. Senge (1997) definitions sees the learning organization as an organic setting in which people engage in a continuous learning process by reflecting on these settings, while people are able to achieve their envisioned results. The learning organization becomes a setting in which organizational and personal objectives can be achieved, and the organizations systematically contribute to their people’s feedback. People become crucial assets due to their knowledge, which in turn contributes to this organizational growth. The concept of the learning organization stipulates the management of both personal and organizational knowledge.

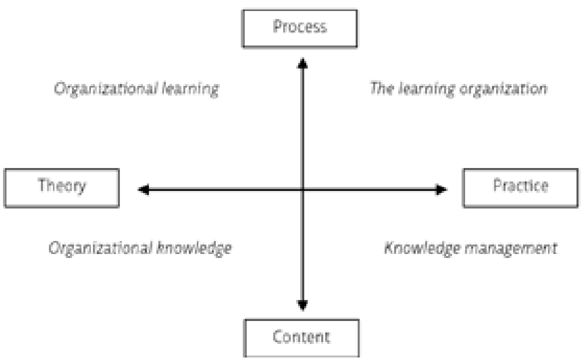

Figure 3
Dimensions of knowledge management and organizational learning according Easterby-Smith et al. (2005, p. 3).

Figure 3 addresses four different realms with different approaches for managing knowledge (Easterby-Smith et al. 2005). It illustrates that knowledge management deals with the content of knowledge to be codified, captured or retrieved, while organizational learning deals with the process whereby the organization acquires the content. Easterby-Smith et al. (2005) noted that critical studies in organizational learning would fit into the knowledge management field and vice versa. This results in an intricate nature of the knowledge literature.

§ 2.2.1 The Field of Knowledge Management

Knowledge management deals with explicit management strategies that focus on processes of acquiring, creating, sharing, utilising, and storing intellectual assets and other stimuli from the internal and external business environments that facilitates an organization to perform successfully (Huber 1991). Skyrme (1997) addresses this explicit and systematic management of vital knowledge, as it is associated to the processes of creation, organization, diffusion, use and exploitation. The field has a practical approach, which attempts to synthesize Information and Communication Technologies (ICT) and aspects of Human Resource Management (HRM) for acquisition of knowledge (i.e. from individuals and/or organizations, internally and externally) to be retrieved later. The aim of KM is to facilitate the creation, access, and reuse of knowledge by people, processes, and technology. It involves the capture, consolidation, dissemination and reuse of knowledge within an organization (Kazi 2005), and deals with the organizational optimization of knowledge through the use of various technologies, tools and processes to achieve set goals (Kamara et al. 2003). (Sveiby 2003) places more emphasis on tacit knowledge and claims that knowledge management is the art of creating value from an organization's intangible assets.

To sum up, KM attempts to propose explicit management approaches for understanding (bringing knowledge to the surface), accessing, (storing knowledge) sharing, and re-generating the tangible and intangible assets of organizations. KM has two dimensions, namely technology (ICT) and people (HRM). The role of ICT is to identify, manage, and share all of the information assets of an organization including databases, documents, policies, procedures and unarticulated expertise and experiences held by individuals in an integral way (Leung 2004). The central goal of the HRM dimension is to increase people's capacities, and to ensure meaningfulness of tasks and diversity in both requirement and learning possibilities that embeds promoting social interaction (Mertins et al. 2001). HRM focuses on the conditions of individuals within a company, whereas ICT focuses on the conditions that enable the sub-processes of explicit knowledge (Jensen et al. 2009). Although the discussions in the KM field synthesize the human and tool dimension, the initial applications often place more emphasis on the tool side. Easterby-Smith et al. (2003) noted that 70% of the publications on knowledge management focus on the design of information technologies. This then illustrates that practice-oriented results can be used in developing systems to capture and disseminate knowledge.

§ 2.2.2 The Field of Organizational Learning

The field of Organizational Learning deals with managing organizational learning (Baskerville et al. 2006). OL perceives knowledge creation as it is closely tuned to the shared value systems of people within a social setting, and it aims to investigate why certain shared, tacit learned behaviour remains in organizations (Weick 1991). Based on the review written by (DeFilippi et al. 2003), there are different theories for managing organizational knowledge such as information processors, behavioural systems, social constructivists, and applied learning.

Information processing theories assume that organizations have cognitive systems. The theories are based on the learning process of individuals in organizations and their knowledge. In this view, knowledge of an organization can be dispersed (the organizational memory as referred to organizations' tacit knowledge).

Behavioural systems theories assume that organizations learn through encoding and interpreting the history into routines through its members. This guides and re-forms the behaviours. This view discusses the importance of environmental selection for learning.

Social constructivist theories focus on learning in organizations as a social context. This view claims that learning is embedded in the relationships and interactions between people. This view complements information processing and the behavioural perspective, since it perceives learning as a socially mediated cognitive process of interpretation. This perspective accepts that the environmental conditions are important as organizations evolve, and it makes sense of itself and its environment. Communities of Practice (CoP) perspective asserts from this perspective since in this perspective learning naturally occurs through a group of people who share similar interests, values and practices.

Applied learning theories propose learning through experience and action. This represents the importance of reflection for individuals. It accepts assignments carried out under time constraints, which contains the work (programmed instruction) and spontaneous reflection on the programmed work by the accomplishers. In this way, learning is facilitated from individual and collective learning. One of the variants of this perspective is project-based learning (DeFilippi et al. 2003).

DeFilippi et al.'s work (2003) stresses that learning perspective strongly emphasizes the social dimension of knowledge to be obtained through individuals and organizations. This refers to both the knowledge creation and sharing processes that occur on two levels, both the individual and organizational. Learning represents a knowledge cycle that occurs in between the two levels. No matter which perspective learning belongs to, knowledge processes in two levels require information processing of both individuals and organizations. Knowledge processes are led by both following and questioning behavioural patterns, which emerge in organizations. Individuals re-frame these behaviours. Knowledge processes occur through the shared interests and practices between individuals within or between organizations. Hence, the field of organizational learning also contains the view that knowledge can be shared across organizational domains naturally by a group of people who are connected by their shared commitments. In this view, organizational knowledge is also fed by external knowledge.

In order to gain in-depth understanding of both fields regarding the goals and interest for managing knowledge, the concept and the dimensions of knowledge need to be clarified.

§ 2.2.3 Concepts and Dimensions of Knowledge

The seminal works on organizational knowledge are Nonaka's work on knowledge creating company, Grant's work on knowledge-based theory of the firm and Blackler's six types of knowledge typology. Grant (1996) approaches organizational knowledge by distinguishing knowledge creation as an individual activity and the organization's role applying existing knowledge into their products and services). Brown et al. (1998) and Easterby-Smith et al. (2003) argue that knowledge is often claimed as an individual property yet a great deal of it is generated and held collaboratively. They discuss knowledge as it is regenerated when the groups are tightly knit as they refer to this formation of a group of individuals. This view is aligned with Alvesson (2001) who focused on the 'connecting' nature of knowledge between communities as stated in the previous section. Similarly, Brown et al. (1998)emphasize the nature of knowledge as it is socially built by the group of people. This view highlights the social dimension of knowledge. Blackler (1995)identifies five types of knowledge as 'embrained', 'embodied', 'embedded', 'encultured' and 'encoded' knowledge, and he illustrates a continuum from personal to organizational knowledge. He discusses embrained knowledge as context-dependent, represents cognitive skills and called 'knowing that' or 'knowing about'. Embodied knowledge is action-oriented knowledge, simply identified as 'knowing about' and related to the physical presence of people (i.e. the tacit way of problem solving), and it partly has an explicit side. Encultured knowledge refers to knowledge acquired through reaching a shared understanding through language-use in socialization, negotiation, or storytelling. Embedded knowledge is knowledge that resided in organizational routines that can be found in relations of systems such as technology, roles, responsibilities organized and distributed in organizations. This typology of knowledge takes the notion of knowledge from individuals to how they respond and perform in specific organizational routines and apply their knowledge as they represent their organizations. Lastly, encoded knowledge refers to information conveyed by signs, symbols (traditionally as books and contemporarily the inputs for information technologies) (Blackler 1995)There are many terms to define and categorize knowledge in organizational and personal contexts. In this study, the three issues that knowledge definitions comprise are emphasized.

Three issues emerge in knowledge discussions within the fields of KM and OL.

1. *The difference between information and knowledge*. According to Nonaka (1994) Nonaka (1994), knowledge is 'justified belief', yet personal and very often (and yet interchangeably) used with the term of information. While information is a flow of messages, knowledge is created and organized by the flow of information, connected to the commitments and beliefs of its holder (Nonaka 1994). Davenport et al. (1998) claim that knowledge is information connected with experience, context, interpretation and reflection, making it therefore a high value form of information ready to apply to decisions and actions. This difference between information and knowledge plays an essential role in defining and discussing the approaches in both fields for management of knowledge.

2. *The relationship between knowledge and actions*. Wiig (1995) defines knowledge as "consist[ing] of truths, beliefs, perspectives and concerns, judgements and expectations, methodologies, and know-how." He states that it is accumulated, organized, integrated and held over periods so that it can be made available when needed and applied to specific situations and problems. He regards the nature of knowledge as personal (judgements and beliefs); operational as enabling problem solving (methodologies); dynamic as it is acquired and integrated over time through experience in solving particular problems. Davenport et al. (1998) discuss this distinction by referring to the actionable nature of knowledge. The emerging issue is the functional nature of knowledge, as knowledge enables people to do something useful. In both fields, doing something useful refers to actions that solve organizational problems. Moreover, these actions can be applied in an organizational context when information is processed and the meaning (embedded in information) is obtained.

3. *The relationship between the personal and collaborative nature of knowledge*. Similar to Wiig's focus (1995) on the personal dimension of knowledge, Bresnen et al. (2003) discuss knowledge as being often tacit, intangible, and context-dependent. They claim that through the 'new problems' introduced in the work environment (with changing roles, responsibilities and the context in which knowledge is required), knowledge as a personal and intangible asset can be accumulated. Quintas (2005)discusses the nature of knowledge as 'communicable' and 'non-communicable'; some forms of human knowledge can be communicated through symbols (i.e. the laws of thermodynamics, names of the star constellations) and once codified, these forms can be interpreted by others by extracting the meaning of the codes. He claims that such interpretations require tacit skills, but the interpreter of the information generally includes what should be conveyed. The definitions target at tacit and explicit knowledge as forming both personal and organizational knowledge. Below these three issues are further elaborated.

§ 2.2.3.1 The Role of Information and Action

The common definition of information assumes a value hierarchy amongst data, information, and knowledge. According to Ackoff (1989), data is raw, it can exist in any form, and yet it has no meaning in itself. Information is a string of data endowed with relevance and purpose (Drucker 1988). Therefore, it is a data with a purpose, with meaning. This "meaning" can be useful, but does not necessarily have to be. Knowledge is the appropriate collection of information, with its main intention to be useful (Ackoff 1989). Nonaka et al. (1995) continues Bateson's discussion on information. They point out that by interpreting information, a new point of view for events or objects can make previously invisible meanings visible or can shed light on unexpected connections (See Bateson,1972 in Nonaka et al. 1995). Information requires a process to obtain the meanings embedded 'invisibly' in the objects. For Davenport et al. (1998) information is a message, usually in the form of a document or an audible or visible communication and moves around organizations through hard and soft networks. Davenport and Prusak (1998, p.1) point out that: "*Knowledge is neither data nor information, though it is related to both*...[the difference] *between these terms is often a matter of degree.*"

Beyond the hierarchy, Davenport and Prusak (1998) claim that organizations make costly mistakes due to the confusion between the terms and their meanings. The confusion results in vast expenditures because of the difference between what organizations expect and what they receive. Data is only symbols, so when it is processed to be useful it subsequently becomes information with meaning. Whenever data or information are put into a context in which 'how' questions can be answered, people then absorb, use and become part of their mental repository, and it then becomes knowledge (van der Spek et al. 1997; Nonaka et al. 2000; Bellinger et al. 2004; Bartholomew 2008). Jewell and Walker (2011) claim that tacit knowledge is more than just facts and information; it is about context, history, and the hidden myriad of interfaces and cause-and-effect loops that explain why something did or did not happen in a particular way.

Those questions that data and information answer concern 'who, what, where and when', whereas knowledge is about 'how and why' questions (Mertins et al. 2001). According to Nonaka et al. (2000, p.25), knowledge is relational: such things as "truth, goodness and beauty are in the eye of the beholder". Kazi (2005) notes that the transformation of information into knowledge takes place through processes such as "comparison", "consequences", "connections", and "conversation", because knowledge is such a complex and 'fluid mix' which is extremely difficult to capture in words, to categorise and to understand completely. The statements above illustrate that there is a structural hierarchy between the three terms. Information has specific aim and function in our world in order to be interpreted. Therefore, knowledge is generated by interpreting information, while information consists of processed data. However, Tuomi (1999, p.7) criticises this view in his 'reverse hierarchy' discussion. According to him, "[d]ata emerges last—only after there is knowledge and information available. There are no "isolated pieces of simple facts" unless someone has created them using his or her knowledge. Data can emerge only if a meaning structure, or semantics, is first fixed and then used to represent information." He highlights the occurrence of data, as it needs to produce knowledge. Similarly, Stewart et al. (1998) point out this cyclic process, as 'one man's knowledge is another man's data'. In another publication, Davenport and Prusak (1998, p.5) bring an 'uncountable' mixture of knowledge, since it is reframed by personal experiences, values (both personal and organizational). They claim that knowledge results in new information and new experiences; and knowledge originates in people's minds and it is often embedded in not only the documents, but also organizational routines and their practices. This leads the discussion to the dynamic process of knowledge, which is incorporated with data and information, which must be placed within new contexts.

In this research, information is treated as a basis for knowledge. Firstly, information is produced by either individuals or groups and it includes to a certain degree, explicit knowledge. Secondly, once information has been interpreted, knowledge is (re)generated. In this interpretation, people either use their existing knowledge as a base, or they seek new knowledge. Through interpreting the information and relating to the existing personal repositories, theoretically knowledge can be accumulated. In this process, people correlate what is new and what is already known, by comparing it with previous experiences applied in/different contexts, and then they check the consequences, or they compare situations within the current context. These processes are performed by individuals and/or groups. That is why conversation and communication are of utmost importance. In other words, information has an object and static form, actors need to interpret, reveal the purpose, and the meaning of the information exchanged in order to make use of the information. This connects us to the role of actions in knowledge discussions.

Perrott (2007) claims that knowledge is "actionable information". For Bouthillier and Shearer (2002, p.4), "while information is basic to knowledge, the latter is more connected to values, belief, and action – and it is not obvious whether individual and organizational knowledge are similar or different". They emphasize the nature of knowledge as it is based on information and after processing, it enables either individuals or organizations to take action. However, Jashapara (2004) argues that actionable information requires a very simplistic view for it to be called knowledge. He claims that knowledge allows us to act more effectively and equips us with a greater ability to predict future outcomes. He used an analogy in which people wear different-coloured glasses.

Alvesson (2001) emphasizes the connecting nature of knowledge for the community. He claims that knowledge (particularly, in social contexts) offers the members of organizations a shared language, and a common way to relate to their world, a resource for interacting with their clients, a means for both creating valid actions and outcomes, and for dealing with complexity and doubt. He describes the roles that knowledge can bring to the members of organizations.

In this study, knowledge is perceived as residing both in individuals (as they are the representative of their organizations) and in organizational routines (as the routines shape and reframe the knowledge of individuals). Knowledge becomes meaningful and useful when it is applied to work, a task, or a problem that organizations need to tackle. Knowledge can be seen as a personal repository, with its development being shaped by the different levels of personal experience, education, culture, or personality, although these do not form the core of this study. The interest of the personal nature of knowledge is that individuals are the actors who are representatives of the organizations and they their disciplinary and organizational knowledge is reflected back to their work environments. These work environments are re-shaped by the actions of individuals. Knowledge is the main interest in this study because it enables individuals to be hired by organizations (to represent them) and organizations to be appointed by clients to the projects. Therefore, individuals act to find valid solutions when representing their organizations through their knowledge and the organizational knowledge that was there before they became involved. By working towards the same goal or sharing the same interests, and by acting to find valid solutions, knowledge may become a means for connecting communities, thus enabling people to obtain a shared language which sustains the communities so that they can re-generate knowledge, beyond what has been based on the personal and intangible repositories. This thus leads the knowledge discussions to the third issue which is the personal (as both tacit and explicit) and organizational (embedded in people, routines, repositories) knowledge, and subsequently the need for knowledge and knowledge sharing in project environments has emerged.

§ 2.2.3.2 The Tacit and Explicit Dimension

Previously, the definitions emphasized the personal and tacit nature of knowledge. The concept of tacit knowledge has been made popular through this quote "I know more than I can tell" (Polanyi et al. 2009)It is mainly the knowledge of how to do things (e.g. how to ride a bike or how to swim). Polanyi exemplifies this by referring to a medical student's experience in reading and analysing the chest of a human body and how the understanding of the student shifted from the initial perception of the X-Ray pictures, which initially are only 'black clouds and shadows', and they only become meaningful later through training. The message intended was that knowledge is not an auditable repository. The intuitive definition is that tacit knowledge is the one difficult to share. Sheehan (2005) claim that 80% of useful knowledge is tacit and it cannot be written down. Although one can question the exact measurement of knowledge, the emerging issue is that one cannot count the extent of knowledge one has and that what one knows cannot be transferred easily. Polanyi's articulation of tacit knowledge was placed in a philosophical context. It has been the primary issue in the Knowledge Management field, after Nonaka (1994) put the tacit and explicit knowledge dimensions in a practical context. They identify tacit knowledge as 'knowledge-not yet articulated' and comprising both technical and cognitive elements (Nonaka 1994). They view socialization as the mechanism, which helps to articulate tacit knowledge. Hence, it is embedded in individuals and derived from the holder's personal experiences (Kazi 2005).

The common perception is that tacit is very personal, acquired throughout time through experience as well as training. The individuals may possibly not distinguish the extent of their tacit knowledge, yet the similar action taken by those individuals within the same contexts may account for the variety and differences in individuals' knowledge. On the contrary, explicit knowledge is knowledge that can be transferred. It can take place in some written forms, be captured or stored in manuals, procedures, databases (Gallupe 2001; Carrillo et al. 2003; Sheehan 2005), and is created through process, procedures and other routines that can be codified (Pathirage et al. 2007)Creating, capturing, codifying, communicating, and transferring tacit knowledge is more difficult than explicit knowledge because such processes are very energy-intensive in intellectual manners (Jewell et al. 2011). In fact, the main discussion concerning tacit knowledge is that it cannot be codified.

Up until now, the scholars' definition has revealed that the nature of tacit knowledge is that it is personal, resides in people's heads, and can be gained through personal experience and that it is difficult (or sometimes it is called impossible) to share, whereas explicit knowledge is a knowledge that can be transformed from a mental capacity to an object form.

In this study, tacit knowledge is perceived as an 'intelligence cushion' that holds new information, transforms it to a new knowledge, and grows in every step of a knowledge process. It is highly personal but has a collective dimension within organizations. The personal dimension is referred to as 'the intelligence base'. This base differs from one individual to another and results in different outcomes, even though individuals follow similar methodologies. This base is built through experience, skills training, and education, which in turn are influenced by talent and skills. The organizational dimension comprises unwritten rules of work practice, socially shared rules that are often not very explicit. One might question this since organizations cannot have tacit knowledge, but work culture. This can be further defined as 'organizational memory'. The term refers to the memories of individuals and shared interpretation processes of historical information that have resulted from implementing earlier decisions and brought to bear on present decisions (Baskerville et al. 2006). The point is that there is a knowledge conveyed in the organizations' routines. It can be either in a form of internally or externally stored archives (Walsh & Ungston, 1997 cited in Baskerville and Dulipovici 2006). This knowledge can be obtained by participating in the work practice and/or first observing then imitating. Besides, tacit knowledge embedded in organizational routines also can be re-formulated through questioning, reflection, and feedback. This refers to the double-loop learning process of Argyris et al. (1978). This loop will be elaborated on in the proceeding section where organizational knowledge is discussed by synthesizing the four issues of knowledge.

In regard to the distinction made between explicit and tacit, these two dimensions of knowledge represent neither a continuum nor the same/different sides of coins. I consider both as if two inter-dependent 'organs' which require each other to function. Tacit knowledge puts intangible and –perhaps- unidentifiable values that both individuals and organizations gain through simply being, existing (i.e. experiencing, education, skills training, etc.) and practising (in the organizational domain) as well as the distinct skills which come through personal skills and the non-identical social and technical structure of organizations (i.e. the roles and relationships between individuals). Through explicit knowledge, people make their presence felt in social and professional environments: because it is 'communicable'. People produce data through knowledge. Consequently, it results in 'someone else's knowledge'. Action require the application of knowledge which comprises the use of data (to be translated to information), the use of information which needs to be interpreted in order to contribute to new knowledge. This represents a spiral shape, symbolizing an organically growing knowledge generation process.

It has been necessary to elaborate on these three issues in order to identify the nature of knowledge, before discussing the different approaches used to manage it. Now it is important to answer the following question: how is organizational knowledge created and shared?

§ 2.2.4 Sharing Organizational Knowledge

Organizations typically start within one knowledge domain, where they develop knowledge through their members; through the individual and collaborative actions on tasks where organizations are appointed to resolve. In Blackler's (1995) discussions, organizations are knowledge processors that generate and share knowledge through their individuals' knowledge processes. Similarly, DeFilippi et al. (2003) claim that organizations store knowledge by accumulating it over time as organizational codes, which constitutes their shared mental model. Huber (1991) also states that organizations generate knowledge through their units. Likewise, Spender (2003) argues that organizations can be seen as an instrument for integrating knowledge and activities. This view establishes the link between individuals and organizations, stressing that individual knowledge becomes organizational knowledge and organizations are the environment in which individuals re-generate and re-shape their knowledge based on the codes in the organizational environment. However, Alavi and Tiwana (2002) argue that knowledge exists in organizations and networks and they exist only in a metaphorical sense.

In view of the discussions above, knowledge sharing in an organizational context starts from the personal and cognitive skill level, and then it is applied in a context through an action (i.e. problem solving). From the personal level to the group level, knowledge is shared by taking part in or observing action. In an organizational context, applying 'what is known' and 'what needs to be tackled' involves a tacit and partly explicit way of solving problems. Physical presence (i.e. face-to-face) becomes important since physicality boosts the socialization mechanisms (i.e. dialogues, conversations) for individuals to acquire knowledge while reaching a shared understanding (i.e. enabling observation and immediate participation). The two processes (applying personal knowledge and acquiring knowledge through socialization) are influenced by organizational routines (i.e. the technology used, the role and responsibilities distributed for solving problems and the work culture that is dominant within these organizations as the explicit and implicit rules of undertaking the work). These processes find themselves eventually in an object form to be conveyed by signs and symbols. This coded knowledge is a result produced by all knowledge processes and yet, it becomes a base for creating and acquiring new knowledge. This is referred to as a continuum by Jasphara (2004:48). In organizations, knowledge is linked with its context to be applied (problems that organizations tackle) and its environment (the rules, routines that form the culture of organizations). However, this is not only a continuum, but it also refers to a cyclic movement of knowledge processes as illustrated in Figure 4.

Figure 4 illustrates the cyclic process of knowledge and knowledge sharing in relation to the information interpreted and processed; the extent of which information interpretation contributes to both the explicit and tacit form of knowledge. Once information has been processed, it can contribute to both the tacit and explicit forms of knowledge. The way that information processing can lead to tacit knowledge is through mentoring, observing, and using imitation processes. The transformation from information to explicit knowledge is through understanding signs, symbols, and the language of the information in order to understand the meaning. By understanding the can be followed so that in the end partly re-generated knowledge becomes data and information from others.

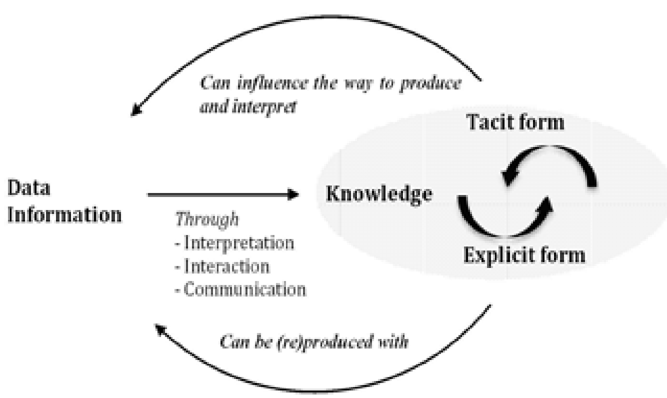

Figure 4
Knowledge generation as two cyclic processes. (© Bektaş).

The discussions so far have illustrated that knowledge comprises processed information through interpretation, reflection and experience, consisting of the results produced by actions in tested certain contexts (contextual differences brings relativeness to the 'justified truth') enabling people to take new action in regard to problems. Thus, knowledge enables people and organizations to do' something useful', to take action and make decisions for solving problems that deal with a social or material phenomena. Knowledge comprises facts that are based on contextual data and/or information exchanged, the values and insights gained through the previous experiences and the 'relative truths', which are applicable until the truth is 'falsified' or re-proved. The truth represents relativeness and the applied conditions in the previous context. Therefore, knowledge has both an objective (based on factual information) and subjective character (personal experiences differing by different backgrounds and skills of individuals). It represents a dynamic and organically growing asset rather than a 'stationary' object. This organic growth is through interpretation, reflection, and social interaction in changing situations where knowledge is used and re-produced such as problem solving and decision-making processes.

Two types of knowledge sharing processes have become evident:

1. Indirect knowledge sharing through tools and artefacts,
2. Direct knowledge sharing through social interaction

§ 2.2.4.1 Knowledge Sharing through Tools and Artefacts

Knowledge sharing can be seen as a remote process, which occurs when sharing captured, codified, and stored knowledge. This process overlaps with information sharing due to both explicit and tacit knowledge to be interpreted. All data and information represent content objects of organizations. These objects are meant to be interpreted by individuals distantly. Through this process, the meanings are obtained and action is taken. There can be several parallel and inter-dependent remote knowledge sharing processes. This can be referred to as the 'division of work'. In other words, work is sub-divided to individuals or groups to be interrelated. This division is done in order to reduce the complex task that organizations are appointed to resolve. Through action, both the interrelation of divided tasks and parallel remote processes are synchronized. This sharing process is greatly dependent on the interpretation skills (the knowledge to interpret data, information and explicit knowledge), and the content of the objects.

§ 2.2.4.2 **Knowledge Sharing through Social Interaction**

Knowledge sharing as a social process occurs through language. By using language, actors share their knowledge by communicating, interacting, and validating their understanding. Without language, non-verbal communication and personal observation and imitation skills become important. In both processes, with and without language, the proximity of those involved becomes important. Knowledge is absorbed by those who actively and passively participate in the actions (either collaboratively or individually). Information plays a role in this type of knowledge sharing since it can be collectively interpreted, and the meanings can be reflected and validated. This sharing process contributes to and targets both the tacit and explicit knowledge of both individuals and organizations. It focuses on social interactions. In social interactions, actors (i.e. designers, managers, etc.) can observe and respond to each other's interpretations and actions. The generation of knowledge and sharing, it is a social process in which verbal/non-verbal language is used within passive/active participation occurs among designers.

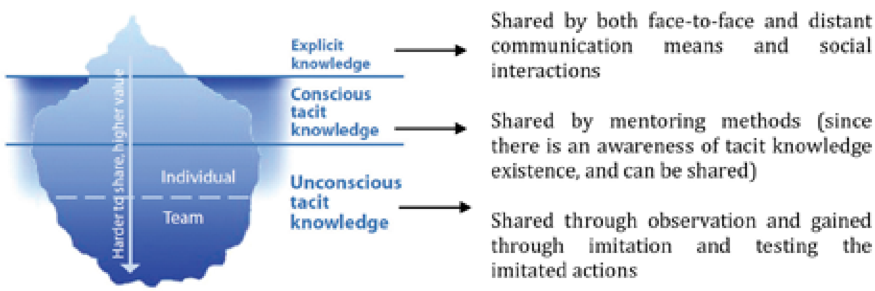

Figure 5
Means of knowledge sharing based on Bartholomew's knowledge iceberg based on (Bartholomew 2008)

Figure 5 illustrates the different mechanisms used in the remote and social processes of knowledge sharing. It shows the relationship of knowledge sharing to the tacit and implicit dimensions. The figure stresses different mechanisms of sharing both tacit and explicit knowledge. Explicit knowledge has tangible outcomes such as the objects of organizations (i.e. reports, drawings, diagrams, manuals, calculations etc.). Explicit knowledge is shared by both distant and face-to-face communication means. Conscious tacit knowledge can be found when people are aware of the tacit forms of their knowledge. One example can be given which shows the differences in people's approaches towards solutions, the knowledge that comes from their educational and personal backgrounds and how that can be distinguished by the 'owner' from others.

In this case, there is awareness of the existence of tacit knowledge and sharing so that it can be realized through mentoring methods. Besides, there is also a significant level of unconscious tacit knowledge found in organizations and work environments. This type is often distinguished by those who observe the others' differing methods, problem solving, and action taking behaviour. This type of knowledge can also be shared without the knowledge of the 'owner' and by observing, imitating, and reflecting these behaviours. What is of key importance in knowledge sharing processes is that there be more than one person who can relate what people know and it is important to be aware of the different sources of knowledge in the work environment, even though knowledge is not intentionally shared. By being aware of knowledge in the existing work environment, discussions can then be developed further on the management of knowledge.

§ 2.3 Management of Knowledge

Up until now, several generic views in knowledge management have been presented. The knowledge concepts, their dimensions, the distinction between personal and organizational knowledge and sharing knowledge have all been discussed. In this section, the general approaches for management of knowledge are reviewed. The objective here is to draw from the various perceptions and implementations for managing knowledge in different industries. This section is meant to prepare the reader so that they can assume a general view on the management of knowledge approaches, before focusing on knowledge sharing strategies for LCBPs. Here, the scholars of knowledge management are grouped into their approaches rather than the fields that they represent. Based on this grouping, two different perspectives have been identified: the object perspective and the community perspective. Below, the two perspectives are described in more detail.

§ 2.3.1 The Object Perspective

The first perspective is referred to as the object perspective by Carlsson et al. (1996) as it deals with the 'supply of knowledge' (Newell et al. 2006). This perspective is also refered to as the 'engineering' perspective (Swan et al. 1999), 'content' (Hayes et al. 2003), or 'IT' perspective (Pathirage et al.).

Knowledge is viewed as a codifiable object, and hence it can be captured and retrieved from repositories (McLure Wasko et al. 2000). The focus lies on codifying the knowledge to be stored, distributed and transferred (Maaninen-Olsson et al. 2008). Technology provides an infrastructure for freeing knowledge from where it is found. Because digital technologies enable us to have access to knowledge, the main concern of this perspective is explicit knowledge.

The object perspective greatly depends on technology-supported implementations, both hardware and software. These implementations have been developed so that they can be part of strategic planning and the management sector, thus serving as challenging business problems for promoting the use of codified knowledge (Leung 2004). Based on Lucca et al.'s (2000) category, hardware technologies form a platform for the software technologies. Hardware requires workstations and personal computers which can access knowledge, as well as servers that can provide a network for the computers, with interoperable designed systems that allow data and information transfer (video/voice/text), and access to both public and private networks (internet and intranet). Within this infrastructure, software technologies are used to facilitate the implementation of KM (Al-Ghassani et al. 2005).

The object-based implementations have two dimensions: 1) a technological infrastructure and 2) an appropriate software program used to operate within this infrastructure. These object-based implementations are called Knowledge Management Systems (KMS). Examples of KMS are web-based platforms for both organizational and inter-organizational knowledge activities through a data 'warehouse' (Wecel et al. 2005), enterprise portals, which are equipped with services (i.e. personalization, content management, folder sharing, and the search for retrieval services) (Chaudhry et al. 2003) or for gathering knowledge into action, training individuals (or users) continuously (Leung 2004).

KMS refers to the different sub-processes of KM. Al-Ghassani et al. (2005)discuss these systems in a broader sense of KM as they claim that knowledge sharing represents collaborative and participatory implementations, even though the technology used is meant for promoting the process. The implementations refer group collaborative systems where the remote participation of people are targeted (i.e. intranets). However, this perspective and its implementations do have several shortcomings.

There are three main shortcomings that can be detected in the object perspective. They are as follows: 1) People and social structures are neglected; 2) the object perspective cannot deal with tacit knowledge; 3) It only adapts slowly to the current work practices.

The first shortcoming is neglecting people and social structures in tool-implementations. The implementations which focus on the object nature of knowledge have been criticised by scholars in the field as little attention has been paid to human resources in these implementations (Leonard and Sensiper, 1998; Holtshouse, 1998; (Heisig 2001; Vorbeck et al. 2001; Zack 2002; Dainty et al. 2005; Pathirage et al. 2007). This raises the discussion concerning the overemphasised prevalence of technology and the social structures which have been neglected, and whose knowledge, in the end, attempts to be codified. Heisig (2001) analysis has been based on 100 cases studies (before 1998) in which he pointed out that IT-based approaches are dominant in KM initiatives and that they ignore tacit knowledge. Ambrosio (2000) similarly points out the high failure rate of KM implementations, which in the past were overly emphasized in many organizations and industries. Senge (1993), Weick (1995), Szulanski (1996) and Bresnen et al. (2003) agree that solely tool-based approaches dominate the KM field and carry with them a danger in that knowledge sharing structures will fail to be created. Not taking people and social aspects into account could result in alignment problems when KMS are used within organizations.

In regard to the possible failures, Gallupe (2001) states that tools should not serve solely as information itself, but they should be capable of handling the richness, the content and the context of the information. Egbu and Robinson (2005) accept the advantages of tools (i.e. enhanced efficiency of exploitation and transparency of sharing), but stresses that such tools hide the in-depth nature of knowledge work. Other scholars such as Lytras et al. (2005), Newell et al. (2006) and Hemati et al. (2009) agree that the tools are commonly implemented but not widely-used. Boer et al. (2002) have experienced that in reality such tools are less promising and, that in practice; the systems remained ‘empty’.

One might anticipate that all these three issues are interlinked and that they refer to the shortcomings on the part of the person involved. Whereas the practical implementations of KM initiatives refer to the use of technology, and the use of people is taken for granted. In other words, people for whom tools are targeted at, subsequently take part in the social structures with their new ‘toys’ and they can form the intended and actual social structures of organizations through their feedback and reflection. Therefore, the second issue, the potential of tacit knowledge’s contribution from both individuals and organizations remains limited. This potentially results in the slow adaptation problems of the tools, since they should actually be part of the people. These problems simply show the concerns that the community perspective must try to deal with.

§ 2.3.2 The Community Perspective

The community perspective involves creating social structures in which knowledge sharing processes can be promoted. This perspective shifts the problem from making tacit knowledge explicit to working out how people are organized around knowledge and how they are aligned with new organizing ways (Wenger 1998; Brown et al. 2001; Bresnen et al. 2003). As the scholars perceive knowledge constructed (generated, shared and primed) through social interactions (Newell et al. 2006), this perspective focuses on 'conditions' which enable knowledge sharing and facilitate 'environments' for the interpretation of both the knowledge codified and the information stored.

This perspective does not neglect how digital technologies can be facilitating (i.e. ICT tools), but it mainly focuses on the social process of knowledge. It focuses on a community concept that refers to a group of individuals who form a knowledge sharing network. These communities consist of different work groups which collaborate together to achieve common goals within a diversity of skills and experiences (Ruggles 1997). These groups are informally bound together by their shared expertise and their passion for joint-expertise, which is a term referring to a network of professionals from across different work-groups and/or organizations who wish to act together within a meaningful negotiation for knowledge sharing act (Brown et al. 1998; Wenger 1998; Wenger et al. 2000). These groups are called Communities of Practice (CoP) and are of interest to scholars in both the content and community perspectives.

Lave et al. (1998) define CoP as people who share work, experiences, values, problem agendas and similar learning opportunities. Due to the fact that they are not a well-defined group, they do not have socially visible boundaries. They are linked through their activities (1998, p.74). CoP members consist of individuals who possess different professional backgrounds and who can perform similar jobs, collaborate on a shared task or work together on a product (engineers, designers etc.) and who have a common sense of purpose. It is the execution of a 'real work' that holds them together (Al-Ghassani et al. 2005). CoP emerges naturally or due to their interdependency (i.e. their division of work). The emerging natures of such sharing communities stem from the commitment they feel towards their work, and they seek shared understanding and the desire to accomplish tasks. In "Knowledge Management in Construction", a book edited by Anumba et al. (2005), 50 per cent of the contributing scholars have acknowledged CoP, and the resulting social and collaborative importance for knowledge initiatives. CoPs are perceived as a tool for sharing tacit knowledge (Pathirage et al. 2005) and (Anumba et al. 2005). Furthermore, Egbu et al. (2005) stress that CoPs are important mechanisms for innovation, since CoPs are informal and interactive groups that cross functional and organizational boundaries and through their social interaction, the tacit knowledge is shared to a certain extent. Sheehan et al. (2005) perceive CoP as a key tool for seeking knowledge within their informal structures, which cut across boundaries (i.e. projects, organizations, and work groups).

Shared aims create 'knowledge sharing practices' which can perform on the intra-organizational level or geographically dispersed groups of people (Dougherty 1992). The emerging character of CoP is that the members are not necessarily from the same organization. The members are individuals who have formed a CoP in order to share knowledge so that it can be in the same work group, organization, or different work units. These individuals perform a shared practice due to the need to obtain the knowledge that the other members have. This brings a different character than the first perspective, which focuses primarily on organizational development and increasing the capacity of organizations within their markets. When organized, CoP can fill the gap for knowledge sharing across disciplines (work units) and/or organizations through the willingness of individuals and by crossing their boundaries (physical, functional, organizational, and social). Although CoP was viewed as a 'technique' by Fruchter et al. (2005) or a 'tool' by Al-Ghassani et al. (2005) in KM, Sheehan et al. (2005) add that CoPs are highly valuable and because the interactivity is high, this provides rapid responses in real-life projects. CoP represents the ideal synthesis between the object and community perspectives of KM for knowledge sharing. Creating and promoting a knowledge sharing group of people who are 'equipped' with tools such as CoP, thus refers to a holistic strategy that deals with the management of knowledge. However, the danger lies in the implementations to create CoP as it occurs naturally and an in an informal way. This danger brings the shortcomings of the community perspective to the surface.

There are also shortcomings associated with the Community Perspective. Up until now, the promising nature of the CoP has been presented. CoPs are natural formations that potentially synthesise the two perspectives of knowledge sharing, which are targeted at people who are facilitated by tools to interact and communicate with each other, access and interpret information. CoPs are social structures that are built around 'work' and cross-functional (as well as cross-organizational organizational) boundaries. On one hand, they represent a high potential to fill the gaps that have occurred within a content perspective. Their natural cross-boundary activities transpire regardless of whether they belong to the same organizations. They naturally emerge and already exist and are 'out there', (Quintas 2005). On the other hand, they 'suffer' from hierarchical structures, and if supressed they go 'underground. Osterlund et al. (2003) discuss this aspect as a potential danger because a CoP is depicted as being largely independent and unconnected. They regard it is as a 'romantic' notion to think that CoPs are only responsible for themselves, and that they therefore do not have (and accept) bosses; these dependencies are only due to the work practice shared by the members in this area. Therefore, the emerging question is whether a CoP itself is a tangible concept that can be explicitly planned within a KM approach.

Another point of criticism is the overemphasis on informal structures found within the community perspective. Hansen et al. (2005) question why the focus is often on the informal structures of CoP and why such little research has been conducted on the different roles and relations of the subgroups which form CoPs. Their research represents a contrary view on 'stronger relationships within the group of people who bring enhanced knowledge sharing practices'. Their research draws that when the subunits have stronger relationships this will reduce the members' boundary crossing activities. Hence, more analysis should be done particularly on inter-group knowledge sharing processes in which the roles and responsibilities are distributed formally. The question remains as to how such naturally occurring groups of people can be organized, since these deliberate implementations should also be taken into account.

§ 2.4 Knowledge Sharing in Large Complex Building Projects

In this section, knowledge sharing at the inter-organizational level in LCBPs will be discussed. The approaches for inter-organizational levels are either digital technologies, which integrate design information (as an interoperable tool and therefore simultaneously performed design processes among people) or which form a knowledge sharing network of people (i.e. CoP) that is independent from being project-specific. The emerging question was "What are the implementations for promoting knowledge sharing across organizations for the on-going projects?" In other words, what are the strategies that can be used to promote knowledge sharing processes among the organizations involved in their current LCBPs?

In order to respond to this question, the design process must first be defined in relationship to the knowledge sharing processes (required to elaborate 'design' a multi-disciplinary product between organizations). Afterwards, the design knowledge for LCBPs can be identified based on the dimensions and concepts of knowledge previously described in Chapter 2.1(i.e. information, action, tacit and explicit knowledge). In the end, the framework of knowledge sharing strategies for LCBPs is conceptualized. After that, it will be possible to detect and to discuss the current strategies, which promote knowledge sharing processes (in this research KSS automatically refers to inter-organizational level) for LCBPs.

§ 2.4.1 The Nature of Large Complex Building Projects

The accepted view is that large complex building projects are unique (DeFilippi et al. 1998; Fredrickson 1998; Grabher 2002; Fong 2003; Turner et al. 2003; Jashapara 2004; Bresnen 2007), temporary and that they represent complex tasks. Their design process is therefore a project-based activity which starts with abstract ideas and ends with concrete presentations (Wang et al.2001). A large number of organizations collaborate to resolve the complex design task. The relevant question is, "How can a complex, unique, and temporary design task be resolved by the appointed parties (architects, engineers, etc.) as realizing a multi-disciplinary design product? In order to answer this question, the design process and the design knowledge need to be identified.

§ 2.4.2 Design Process

According to Cross (1982), design starts with the client and their brief. The brief informs the managerial and designer parties about the design problem. Cross (1982) describes design problems as completely novel, a fixed goal with constraints. Based on the brief, the appointed designers start generating ideas through sketches and elaborate on them to prepare the final artefact. In this process of preparing the final artefacts, designers exchange their ideas, artefacts, and sketches so that the design fulfils the multi-disciplinary requirements. In the process of designing, design knowledge is generated by the exemplars created by previous designers.

Cross (1984) approaches design as a heuristic process that requires previous experience, general guidelines, problem statements, and rules of thumb that all lead designers in the right direction. Nevertheless, he adds that it is not a succeeding promise. He identifies the process as it starts by exploration, generating the concepts, then evaluating and re-generating the concepts (or elaborating) then communicating. Communication does not solely entail interacting with other parties, once a concrete artefact has been produced. He defines sketches and artefacts as a dialogue between 1) the problem and the solution area and 2) between internal and external domains (i.e. among designers, disciplines, and organizations). Different scholars have proposed different models for the design processes such as Jones (1984), Archer (1984), Pahl and Beitz (1984). These models vary from being prescriptive to integrative. In prescriptive models, Jones (1984) distinguishes design processes using three basic structures 1) an analysis of all the requirements, 2) synthesis through attempting to find possible solutions with the least compromise, and 3) evaluation as checking the accuracy with the requirements and the proposed design.

Archer (1984) approaches the process as being divided into three broad phases: 1) analytical, 2) creative and 3) executive. He refers to the design process as a 'creative sandwich' as it comprises objective and systematic analysis (could be thin or thick) and somewhere in between a creative process can be found. He expands the design process as comprising 1) the programming of crucial actions and issues, data collection, analysis as identifying sub-problems, synthesis of sub-problems for the outline of the proposals, development as an elaboration of the outlines and communication which produces documentation such as drawings.

Pahl and Beitz (1984) approach the design process as being more detailed and they assign four stages. They are regarded as 1) the clarification of the task, 2) the concept design in which principle decisions are taken, and functional requirements are set, 3) the embodied design in which designers produce the design in technical and economic considerations by determining the layout, and 4) conceptual forms and concretizing the decisions taken in the earlier step (if not discarding).

In March's model (1984) and the VDI ('Verein Deutscher Ingenieure') guidelines, design is conceptualised as an overall problem and an overall solution. Both the overall problem and overall solution refer to the central design. The overall problem is divided into sub-problems and then into individual problems. The solution starts from an individual level and then it is connected to sub-solutions and subsequently it is inter-connected to the overall solution. Yet, design is not a linear process from problem to a solution. There is a constant iteration between problem and solution area. Cross (1999) identifies this iteration in an integrative model rather than by using traditional design process models. In an integrative approach, designers explore problems and solutions together. Although there is a logical reasoning from overall problem to sub-problem division, and then to reach the overall problems, there is a commutative and symmetrical relationship between the overall and sub-problems and solutions as illustrated by Cross below in Figure 6.

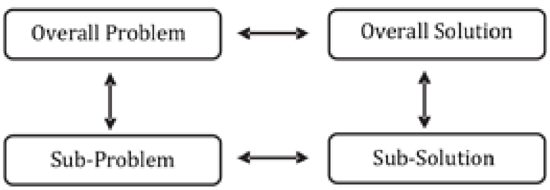

Figure 6

Cross' (1982) symmetrical relationships of problems and solutions as co-evolving.

§ 2.4.3 Design Knowledge

Sketching is essential for design knowledge throughout the design process. It forms the design product as a final artefact and becomes a means for externalizing both ideas and problems of actors. Therefore, by sketching the knowledge of designers it is externalized and made tangible. By tangible objects such as artefacts, actors interact and reflect their ideas with the objects, and therefore more ideas can be captured. Cross (1982) claims that sketching can be seen as a dialogue between designers and design, and between the design problem and the current knowledge of designers relating to the problems. In these dialogues, artefacts become a means of communicating, interacting, and exchanging ideas among actors. Artefacts eventually are embedded in the design information and design conversations.

While designers are sketching, they are also dealing with problems in a variety of abstraction. Design, therefore, becomes a process in which tangible outcomes are produced while problems are being solved. He claims that sometimes the initial ideas are discarded while more knowledge is integrated. This refers to a design process, which first starts with initial concepts, and while elaborating on these concepts, more (multi-disciplinary) knowledge is required and it is subsequently integrated. In certain cases, the initial concepts do not answer the input gathered by other parties (i.e. mainly other disciplines). In these cases, the initial concepts are revised either so that the multi-disciplinary input can be positioned in the design solution or it can be discarded. This illustrates the processes of generating knowledge through artefact production and exploring the problem statements and it demonstrates how a constant iteration between the design as a problem and the design as solution proposals can emerge. The iteration between problem and solution elucidates how the knowledge space of designers expands through sketching (which enables communicating the problems and solutions either internally or externally), while at the same time other designers' input can be gathered and included. Then the proposed concepts can be evaluated in the regard to how they form the design (Cross 1999).

In his further work, Cross (1999) stresses design as a conceptual thinking process which designers have based on previous examples and which evolve each time with a new problem statement provided by the clients. Throughout the process, designers generate project-specific design knowledge and in this process, they see whether they are able to elaborate on their initial ideas or whether the ideas remain limited and unresolved. Using previous experience is also important 1) to process the information and 2) to anticipate the other disciplines/designers' input which can be crucial. In the design process, where design knowledge is generated by actors, actors have different abilities, approaches towards design problems' resolution and collaboration. Actors therefore have different methodologies for generating, sharing and applying knowledge and producing the design objects as the multi-disciplinary design knowledge is embedded. Cross (1982) views this as an increasingly complex, temporary and unique design task, in which the designers' previous experience may be irrelevant and inadequate, and in which there is a more systematic approach needed to develop team work with many specialists collaborating and contributing to the design. He stresses (1982) the design process as being 'ill-defined', and the way people are involved in the design and how they perform the design process needs to be understood. The ill-defined nature suggests that design is as a problem that designers tackle without having a very clear goal, and a clear answer (or one exact answer) or rules that create a specific answer. He sees design as the iteration between the formulation of the problem and the creation of solution concepts. The structure of the problem contains sub-problems which are inter-connected and which may create inconsistencies once they have been integrated into a final design. In this field of study, namely, large complex building projects, the design process naturally becomes more complex due to the number of subtasks and the multi-disciplinary knowledge required.

§ 2.4.4 Design in Large Complex Building Projects

In large complex building projects, design represents a complex problem and a final artefact, which requires a large number of organizations. The organizations are appointed according to their domain knowledge that results in their final artefacts. Their appointment represents the first division of the main design task into disciplines. Thus, organizations are appointed to conduct parallel design processes and to deliver their artefacts to the clients and to each other in order to integrate the sub-solutions. These artefacts vary depending on the stages of the projects. In traditionally contracted projects, there are two initial phases, namely, design and construction. The design phase represents the period from the conceptual design until the final design in which the contractors are selected to realize the projects. In the construction phase, the detailed design is prepared, based on the specifications agreed and then submitted as a final design. In this research study, the focus is on the design phase. Therefore, the organizations are appointed to deliver their final artefacts in forms of architectural design, engineering design, or any form of output that is needed and where consistency forms part of the main solution. This shows how organizations have several design processes in which there is a constant exchange of artefacts and interactions. Organizations might have multi or mono-disciplinary responsibility, depending on their knowledge and contractual agreements with the clients. Nevertheless, this does not mean that each organization has its own iterative processes in which several artefacts are elaborated through internal and external feedback. A synchronization of various design processes in which organizations are expected to collaborate can thus emerge.

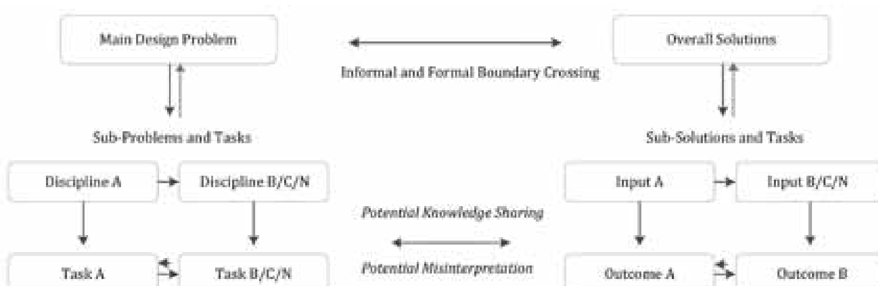

Figure 7
The design process as an overall problem and the division of work as sub-problems and sub-solution integration (© Bektaş)

Figure 7 illustrates the division of the main design problem into the disciplines (division of labour) in a project environment. It stresses that each division (discipline) is responsible for its own output (i.e. design deliverables as an artefact or disciplinary object). In the design process, disciplines provide input to each other; while they work on their outcome (see Outcome A/B/.../N). They provide these inputs through formal and informal boundary crossing such as digitally exchanging their drawings/reports or verbally through conversations etc. However, when actors exchange their objects without having had much social interaction, potential misunderstandings can occur. In solving the main design problem synchronously, organizations exchange their artefacts during the process, and they interact to exchange the insights that supplement the objects exchanged. This exchange (both social and physical) externalizes the discrepancies in how artefacts are produced and how problems are solved. This leads us to the differences found in the design team. First, the concept of design teams needs to be defined.

Organizations involved in projects form cross-functional design teams. The team consists of representatives of the organizations involved to pursue the organizational objectives and to fulfil the tasks as defined by the clients. Huang et al. (2003) discuss that the teams are formed for strategic planning and used to generate a consensus through collective input, investigation, and negotiation in creative tasks. They draw attention to their complex nature in terms of their varied interests, the division of labour, and their boundaries between the work units.

The teams are formed in order to resolve the tasks that cannot be dealt with by one discipline and the people in the team fulfil the overall task by integrating their differentiated knowledge both internally within the team and externally with the various stakeholders of the projects (Huang et al. 2003). The teams comprise individuals (single representatives of their organizations) and/or design crews whose professions consist of various disciplines. These disciplines may belong to different organizations that have been contractually bound to one another. Hence, the members have legal responsibilities and dependencies with each other throughout the project duration. This brings a multi-disciplinary, organizational, and temporary structure to the teams. The members greatly depend on the most current design information to work out their own design tasks (Wiegeraad 1999; Kvan 2000). They elaborate on the design by collecting, sharing, and transforming the information about the design (Otter 2007). The information processes need to be applied to the design work so that it can answer the multi-disciplinary problems. Each designer carries out their own responsibility in the design crews. Once their ideas become concrete, they exchange their solutions recurrently in order to integrate each other's outcomes as partial design solutions. In order to solve the main design problem, partial solutions from different design disciplines are integrated with respect to the project requirements (such as cost efficiency, safety, constructability, energy saving, etc.). When elaborating on the design, the team members communicate both synchronously and asynchronously by using the available means of communication (Davenport 1997, Donker 1999). This leads to remote and active knowledge sharing processes as mentioned in § 2.2.

Reviewing these concepts, particularly in LCBPs, has made it clear that design is a collaborative activity among actors who are involved in projects in which they use their disciplinary knowledge. The actors provide disciplinary input in order to produce 'a design' that integrates multi-disciplinary knowledge in order to achieve the project objectives. Since design from the conceptual to the detailed design phase has evolved in the sense that more aspects are integrated through elaborating on the requirements, the design decisions are taken within an evolved design rationale. Design decisions and rationale in a design team are most frequently communicated during informal design activities, especially in the conceptual phase. Informal design activities occur most often through informal media, such as sketching, verbal explanations or gesture language (Fruchter et al. 2005). The type of communication used is more important when transferring tacit knowledge than it is with explicit knowledge. For tacit knowledge to be transmitted, interpersonal communication is of utmost importance, as team members share tacitly held personal experience through dialogue (Fong 2005). It became also clear how the design process starts and where design knowledge is re-produced in each new unique project context. The emerging question is where the design knowledge is shared and re-produced to create knowledge in on-going projects. In other words, what is the process of knowledge sharing that starts from the designers' individual and disciplinary to the multi-disciplinary level? Below, the design teams' processes (interaction and artefact production) are linked to knowledge sharing processes (both tacit and explicit).

§ 2.4.5 Knowledge in the Design Process of Large Complex Building Projects

Knowledge in the design process has individual, organizational or project dimensions. There is a growing loop between the three dimensions (as organizational learning literature draws attention to this loop as being either single or double loop learning processes). In large complex building projects, the organizational knowledge that has been accumulated during the projects involving organizations forms the starting point for these organizations to be appointed in new projects. Once organizations have been appointed, their tasks are divided into disciplinary parts in which the design crews are required to perform and produce the relevant artefact. Within the crews, the divided task is again sub-divided so that individuals can perform parallel sub-processes. At this point, individuals start to approach their problem within the wider context that the design crews have agreed upon. Individuals can then synthesize their own current knowledge drawn from previous experiences with the new information that has been supplied in the brief and by other parties. These parties are both their own disciplinary crew members and the other disciplines, which serve to provide design information for each other. This demonstrates how individuals juggle the cross-disciplinary interaction that occurs both when exchanging objects and social interactions. Individual knowledge resides in both the minds of the designers, engineers, managers (as knowledge workers) and their sketches and artefacts. One might claim that it is the basic unit of the knowledge sharing process, since they focus on their sub-problems and generate specific solutions to be exchanged. In these individual and sub-processes, each individual as they cooperate with his or her task group may come up with different solutions due to how they understand the design methodology in relationship to each task. This understanding may be built on their unknown depth of tacit knowledge (mostly unknown by others, possibly by themselves as well). The understanding is the core part of an individual's knowledge. This core knowledge consists of both the discipline specific explicit (facts) and implicit (routines, judgment, etc.) knowledge held by an individual. Hence, individuals are involved in a given project so that they can apply their previous knowledge to new contexts as well as to generate project-specific knowledge, which may be reused in future projects. In other words, individuals perform the design processes based on their personal repertoire of disciplinary and organizational knowledge.

Through elaborating on the design in each next phase of design, they collaboratively produce project knowledge. Project knowledge is embedded in both the final artefact and the collaborative design processes in which various types of organizational knowledge are externalized. By gaining project knowledge, organizations can add to their sectorial knowledge. Anumba et al. (2007) define project knowledge as the knowledge required to conceive, develop, realize, and to terminate a project, but it is also constituted by multi-disciplines and assembled through the realization of construction.

Project knowledge builds sectorial knowledge, which in turn becomes external (i.e. commercial, educational, health, etc.) and takes part of organizational knowledge. External organizational knowledge strengthens the position of the firms in the market. This is a knowledge-sharing loop starting from individuals, involving their groups within their organizations, evolving, and accumulating with each new project. Although I treat individuals as key knowledge producers in both the organizational and project setting, they are blended in a design process as an inter-organization-dependent activity. After identifying the design processes within the design teams, now I will list the components of knowledge sharing within the design teams of large complex building projects as tools and people as these were the focal issues of the management of knowledge (see § 2.2). Firstly, the role of tools and the artefacts that are produced through the tools in knowledge sharing are described. Secondly, the role of people and the role of actions and interactions in knowledge sharing are described in the design process of large complex building projects.

§ 2.4.5.1 The Role of Tools and Artefacts

Tools that assist knowledge management can be generally classified as IT-based and non-IT based tools in the design process. As Anumba et al. (2007) claims, they are required to support sub-processes of knowledge management such as locating, sharing, and modifying knowledge. IT-based tools provide infrastructure to formulate approaches for knowledge workers to use and to exchange their knowledge most efficiently within effective communication channels (i.e. CAD systems, information repositories, product and process modelling efforts, intranets and other software packages developed for particular design and construction problems, communication tools). The tools focus on explicit knowledge and the way that knowledge workers are to be equipped with the tools. Non IT-based tools aim to extract both tacit and explicit knowledge. Procedures, guidelines, reports of the projects, sketches, and minutes embed knowledge and they do not require particular expertise to learn how to use and understand them. These tools need common languages and particular patterns that actors can follow. Brainstorming, training sessions, and meetings (both informal and formal) are methods that can be used to capture and exchange knowledge. In this research study, tools and technology are grouped together as one category, which supports the knowledge sharing processes digitally. The concept of non-IT based tools can be categorized as the procedures (rules, guidelines, reports) and the interventions such as partial strategies, and the tactics of practitioners used for particular knowledge sharing enhancement (i.e. brainstorming, meetings, trainings etc.).

In the design process, artefacts are the tangible objects that embed both disciplinary and organizational knowledge. Up until now, the overall design solution has been viewed as a final artefact. Throughout the design process, artefacts can be impartial, incomplete but nevertheless they are often assumed to cross functional boundaries to communicate and interact with people. They are boundary objects that travel across the disciplinary crews within design teams. Design information and boundary objects convey knowledge in a project environment. In this study, boundary objects are perceived as an important medium for knowledge processes as they contain disciplinary knowledge. In a project environment, data represents factual documents (i.e. the importance how passenger flow within a transportation context, site conditions, fire/safety regulations of authorities in generic building context, etc.). Information represents the use of data within the project context such as the flow of passengers in a project location, the reports on the site and soil conditions, the user behaviours in the area of the project location and the importance of the impact such facts have on the design process). This leads to the term 'design information' which needs to be provided by the organizations (actors) involved in the design process and exchanged among them. This refers to a process of crossing functional and organizational boundaries. Therefore, design information takes places in the objects that such organizations produce. The objects carrying design information are called boundary objects.

Star and Griesemer (1989) define boundary objects as inhabiting several intersecting social worlds and satisfying the informational requirements of each world. They add that the boundary objects are structured weakly for shared use and that they become strongly structured when used individually; and they have different meanings in different social worlds but their structure is similar enough to more than one world so as to make them recognizable and to function as a means of translation (Star and Griesemer 1989; Gal et al. 2004). Gal et al. (2004) brings the distinction of boundary objects in socio-technical projects, as they are primary and secondary (Garrety and Badham, 2004), ideal and visionary (Brier and Chua, 2001) whereas Carlile (2002) distinguished among the syntactic, semantic, and pragmatic as these require different types of boundary objects (Gal et al. 2004). The primary objects refer to the technology itself – the material artefact around which an activity is organized, and the secondary objects refer to other physical or abstract entities that enable communication across social groups such as organizations (Gal et al. 2004). Ewenstein and Whyte (2009) distinguish boundary objects as 'epistemic objects' (as basing on Rheinberger , 1997) and 'technical objects'. Epistemic objects are abstract, incomplete and appear in temporary instantiations, whereas technical objects provide a frame for the objects of inquiry, and involve the taken-for-granted equipment and tools (Ewenstein and Whyte 2009). In this sense, boundary objects in the design environment are 1) tools which help designers In the design environment, boundary objects are 1) tools which help designers (as representatives of organizations) to produce artefacts containing data and design information and/or visualize artefacts which contain design information to be exchanged (both virtually and physically), 2) artefacts as physical and tangible objects which contain design information produced physically by project actors. Several examples of these tools are CAD, calculation, planning programs, digital repositories or any KMS. For artefacts, the examples can be given as design precedents, sketches of actors. etc. They are more visual objects, which illustrates the concept of problems/solutions.

§ 2.4.5.2 The Role of People and Social Interactions

In the design process, design team members represent the knowledge actors who process and produce information, who generate and share knowledge, and who take and reflect on actions in the design environment. They represent various disciplines and they combine both the disciplinary and organizational knowledge. I perceive people as the main engine of the knowledge sharing mechanisms that produce artefacts, that interact, and that create overlap between the solutions. They take part in projects as representatives of their knowledge domain. They process and reproduce data and information, and provide other members of organizations with this same data. They convey their work routines (i.e. disciplinary and organizational), observe the similar/different routines, reflect, and re-frame their environments. They form the knowledge sharing practices through their actions. They are clients, advisors, project managers, architects, construction managers, design, and engineering group members, specialists or general contractors and they are all knowledge actors. Therefore, people are the ones who have interdependencies in the project environment. They use interaction to meet their interests and they are involved in a dialogue and debate with multiple disciplines. This leads us to actions and interactions in the design process.

In the design process, actions give evidence regarding the existence of knowledge. Through actions, individuals proceed from their current problem status to find solutions. As explained earlier, this is not a linear process but an iterative loop. In this loop, people take decisions (either in both disciplinary and multi-disciplinary wises) and apply them to actions in order to proceed. In order to take decisions and actions, design input is provided through artefacts and social interactions. This sets the interrelations between artefacts, people, tools, and interactions. As a consequence of the decisions and actions taken, knowledge (both individual and organizational) is reframed and primed for adding new knowledge during the project course. Actions set a link to the interactions, since it requires a collaborative act with processed artefacts and disciplinary solutions. In regard to the two types of knowledge sharing that were discussed in § 2.2, in a design environment social interactions are performed internally (among individuals placed in the same design crew or in organizations) or externally (among individuals in a multidisciplinary project team, or organizations). Regardless of being external or internal, these interactions can lead designers to both informal and formal knowledge sharing.

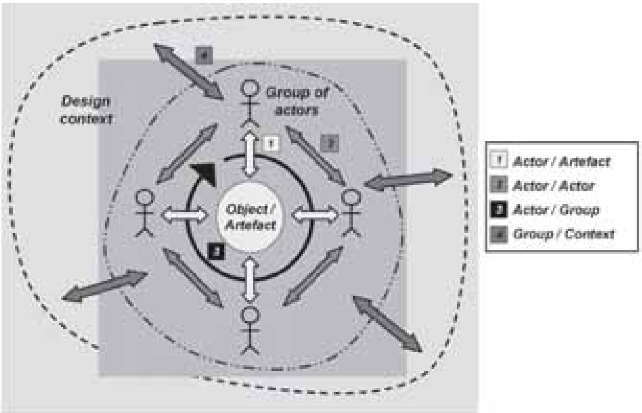

Figure 8
Design actors' interactions with the context of work (Robin et al. 2007, p.189)

Informal or formal knowledge sharing is a design process which occurs at different levels: 1) sharing between designers within their design crews/organizations, 2) sharing between project actors across organizations, 3) or a combination in which sharing occurs between project actors on a managerial level and sharing occurs between managers/project leaders and their design crews. Robin et al. (2007) use Girard et al.'s four types of interaction between actors that involve the contextual elements and eventually reflect these as the evolution process of the design. Figure 8 illustrates these four types of interactions: 1) actor/object of design, 2) actor/actor, 3) actor/group and 4) interaction between the group of actors and the context (Robin et al. 2007). The first type concerns the interactions between the actor and the object of design (the design artefact). In this case, it is necessary to analyse the actor's impact on the evolution of the design artefact definition (Robin et al. 2007). When an actor interacts with the design object, the actor starts to produce ideas through drawing sketches, diagrams, writing words or equations. This is a form of externalizing his/her knowledge and enables other actors to participate in a passive knowledge sharing because the participation of the other actors is restricted to the process. It is passive in that the Knowledge Sharing is based on the other actors' skills of observation and imitation. In this form, an actor who externalizes his/her knowledge also states his or her own method/techniques for finding solutions (their way of doing 'things'). The ones who are present in the environment receive information concerning both mind-sets and they can observe the behavioural changes of the actors whereas the others are not able to do this. In other words, the actors observe the practice of the actor interacting with the design object. They see how 'the other' processes the information, and what the cultural differences (both disciplinary and organizational) are. They process the information gained through the observation process, and reflect it by imitating this knowledge in a group environment. Therefore, this process is an example of passive Knowledge Sharing.

The second and the third type of interaction focuses on the individual actor and his/her individual relationships with others members of the group (Robin et al. 2007). In both forms, there is an active participation performed by using verbal communication, sketching, and dialogues. This interaction leads us to a more active way of sharing in which the spontaneous reactions of the actors are accommodated. These reactions provide confirmation of the shared knowledge of actors that leads them to achieve shared understandings. In this type of interaction, the environment in which the action occurs and the actors take part becomes important. This environment has an influence on the actors and it is important to identify the factors that create a good state of mind and motivation in the group (Robin et al. 2007). The state of mind and motivation of the actors have cultural and social influences that are caused by disciplinary and organizational differences. Disciplinary differences include both specialist knowledge and the different mind-sets of designers (the way they perceive the tasks, process information and take action) which are reflected in their practices. One can be process-focused in striving for a better end product; another can be conclusion-focused (task-focused), concerned with reaching the solution necessary to take the design task to another stage. Schön's (1983) 'reflective practitioner' concept can serve as an example for the process-focused actors. Such designers juggle variables, reconcile conflicting values, and manoeuvre around constraints – a process in which, although some design products may be superior to others, there are no unique right answers. You discover more about the problem as you try to solve the problem (Jossey-Bass 1987). For examples regarding the end-result oriented actors, clients or more managerial level of designers can be included. The result of the design processes is the main concern of these actors, not the design process itself. The process-oriented actor is the one who strives for the highest quality final product, while the solution-oriented actor is the one who wants to fulfil the 'workflow', and meet the pre-defined project goals. In other words, the actor's chief concern is the impact or the consequences of the design development, rather than the design development process itself.

The last type identifies interaction between the group and its environment (Robin et al. 2007). This interaction accommodates both actor-objects and actor-actor interactions. It is a process which consists of the actions of actors such as externalizing their knowledge through objects (non-verbally and a passive way of sharing), reactions of the actors, their observations (passive way of sharing), commenting and participating (active way of sharing through language use), sketching, dialogues (through active use of communication means), and placing the shared ideas within the design context together. The externalizing knowledge (individually), observing how the others externalize it (individually), reflecting/commenting on this process and interactively participating in the sharing process through language use (interactively) and applying decisions together in the design context (collaboratively) refers to an environment which accommodates these actions, and this is a knowledge sharing environment. In this environment, disciplinary knowledge is shared; interdisciplinary knowledge is generated then integrated through the four modes of interaction. Therefore, the group dynamics, the internal and external factors all have an influence on the group and on each actor and each step of the evolution of the group need to be defined (Robin et al. 2007).

1 *Actor to object*: Individually realized – discursive (expanding individual ideas may not have a single focus) –intermittently occurred – no boundaries are crossed.
Actor and object interaction leads to passive participation of an actor in a group, as actor interprets the meaning of the object individually. This results in passive knowledge sharing not only through actors' individual process but also through the group members' observations and imitations of 'the way of doing things'. The observations and imitations provide chance to share tacit knowledge (externalizing disciplinary knowledge in a 'disciplinary way' i.e. sketching, calculations, equations).

2 *Actor to actor*: Interactive (reciprocal) – elaborative – mutual (collaboratively) – boundaries are crossed.

Actor to actor interaction leads to active participation of actors in a group with each other. It leads to active KS, as this interaction allows for checking the other person's understanding through active language using such as dialogues, conversations, and sketching. These active language uses have a reflective nature of the shared knowledge that supports confirmation and validation of the shared understanding between disciplines.

3 *Actor to group*: Iterative –decision-focused –confirmative

Actor to group interaction requires both active and passive participation in a group; Ideas are generated collaboratively and the dialogues lead actors to how to apply the shared knowledge into own disciplinary context, groups' reaction, and have chances to confirm whether the shared knowledge and its application is right. This confirmation is through both active use of language (dialogues, brainstorming, discussions/conversations through spoken words) and passive use of knowledge (sketching, diagramming, equations through written symbols).

4 *Group to context*: within a disciplinary crew /conclusive

The group members synthesize the meanings gathered from each other in order to position the decisions, insights, and design solutions collaboratively into design context. Each actor synthesizes knowledge shared with his/her own knowledge and puts it into his/her own disciplinary context. Thus, the contextualization occurs both individually (mono-disciplinary) and collaboratively (across disciplines). Group concludes the decisions taken through the previous interactions and clarify how to apply the decisions onto the design context.

The four types of social interactions in relation to artefacts, people, and tools show the importance of the environment in which knowledge sharing processes occur. Robin et al' s (2007) interaction types discuss the physical environment that creates proximity to the people who interact. The four types of interaction that leverage the knowledge sharing processes can be performed either remotely and/or proximately. In remote social interactions, the support of tools becomes important, since tools create virtual environments in which people interact. In proximate interaction, the properties of the environment carry an important role, since their layouts, participants, and duration influence the interactions. Knowledge sharing processes occur in both tool-supported and physically supported environments. Thus, the environments in which knowledge sharing processes potentially occur due to the components (i.e. people, artefact, actions taken/decisions given, social interactions with/out tools) are called Knowledge Sharing Environments (KSE) in this study.

§ 2.4.6 Knowledge Sharing Environments

Knowledge Sharing Environments (KSEs) can be both virtual (tool-supported) or physical (co-located) environments accommodating boundary objects (both informal artefacts and formal design precedents), people (having both tacit and explicit knowledge), interaction for knowledge sharing (observation/ imitation and socialization/ confirmation). KSEs are physical or virtual settings, which facilitate project actors to exchange their insights, understandings, and perspectives so that the actors reinforce their knowledge about the project's course, and so they are aware of the other actors' agendas and objectives. Through a knowledge sharing environment, the actors' work processes can be synchronized. A potential knowledge-sharing environment (KSE) that accommodates;

- Boundaries crossed (functional, disciplinary, and contractual),
- Actors existing with their ideas and knowledge,
- Objects (design issues/problems) to be discussed and/or developed,
- Design context in which the object is reasoned and placed by actors,
- Mechanisms to share knowledge through their interaction and participation while crossing their boundaries.

KSE therefore require the following conditions:

1. Knowledge can be expressed through passive participation – leading to passive KS through both observations and imitations of 'the way of doing things' – related tacitly (externalizing disciplinary knowledge in a 'disciplinary way' i.e. sketching, calculations, equations). Boundaries can be crossed through active participation– leading to active KS (which allows for checking the other person's understanding) through active language use (i.e. dialogues, conversations, sketching which all have a reflective nature of the shared knowledge that supports confirmation of the shared understanding between disciplines).
2. Ideas are (re)generated for how to apply the shared knowledge in one's own disciplinary context, groups' reaction, and confirming whether the shared knowledge and its application is right through both active use of language (dialogues, brainstorming, discussions/conversations through spoken words) and passive use of knowledge (sketching, diagramming, equations through written symbols).
3. Artefacts are interpreted both individually (mono-disciplinary) and collaboratively (across disciplines) when a group (i.e. design team) finalizes the decisions taken through the previous interaction.

The four types of interaction and participation are accommodated in KS environments. Beyond each interaction, designers carry a certain level of boundaries due to the discipline and organization they represent. The interaction (active and passive participation) is highly dependent on the 'thicknesses' of these boundaries. These boundaries have an impact on designers' behaviours due to the legal, functional, psychological linkages between/in organizations. Therefore, the ways that people interact within KSE become important in turning a multi-disciplinary environment that fulfils the same components to form a KSE, which accommodates knowledge sharing processes. This highlights the importance of strategies that focus on creating environments that provide knowledge sharing processes through supported social interactions. The important question is what the strategic approaches that create KSEs and promote knowledge sharing among actors are for LCBPs. This leads to project-specific knowledge sharing approaches.

§ 2.4.7 Project-Specific Knowledge Sharing Approaches

There are two types of approaches that deal with knowledge sharing in projects, namely tool and people oriented. Both approaches cope with inter-organizational collaboration among the design team organizations. These approaches vary from establishing legal frameworks for the organizations to computer-supported solutions that are proposed to boost their virtual interaction. The legal frameworks consist of integrated contracts bonding the organizations to each other to collaborate. The tools used are the new digital technologies that prescribe new ways of working among design organizations that take part in the project environment. Some examples of the former approach are Integrated Project Delivery (IPD), Integrated Design, and Delivery Solutions (IDDS). Other examples for the second approaches include Virtual Design and Construct (VDC) and Building Information Models (BIM).

For the contract-focused implementations, the Integrated Project Delivery has been defined by the American Institute of Architects (AIA). It is claimed that "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction" (AIA 2007). This integration is reached through agreements and contracts between the members of the multi-disciplinary design team, as well as the use of current computer technologies and methods to define and measure project goals. IPD attempts to be implemented throughout the overall process starting from the conceptual design to the construction of projects. IPD focuses on the integration of insights gained through the people, their organizational processes, and the practices in order to optimize the results and reduce overruns (both time and costs). The legal agreement among design team organizations is the mean (set in managerial level) for the collaboration of actors.

The International Council for Research and Innovation in Building and Construction describes an alternative initiative that has been called Integrated Design and Delivery Solutions (IDDS). IDDS focuses on: "the use of collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process inefficiencies and to enhance the value delivered during design, building, and operation across projects" (CIB 2009). In order to reach this goal, IDDS envisions a holistic approach that attempts to integrate design processes, technologies for collaboration and automation and experienced project teams (CIB 2009). Similar to IPD, IDDS highlights the computer technologies that are considered as a crucial means for achieving collaboration with the organizations. IDDS draws special attention to the people who actually perform the collaboration and integration. Yet, both approaches still focus on overall project processes when attempting to define new business project models rather than targeting the design process. This makes both IPD and IDDS highly descriptive and general (See Scharma, 2011). However, both acknowledge that by using computer technology for design team integration leverage can be gained. VDC and BIM specialize more on detailing the use of the technology. Below tool and technology-oriented approaches are further elaborated on.

§ 2.4.7.1 A Tool-oriented Approach

Tool-oriented approaches focus on digital technologies therefore computer mediation in project environments. Examples of such approaches are CAD systems, and particularly Building Information Modelling (BIM). Computer Aided Design (CAD) was first developed and applied for the production of 2D computer drawings; in the 1990s, 3D visualization or virtual modelling became available (Issa 2003). Currently, BIM is being explored and practiced as applying digital technologies for team integration. BIM is a computer-based virtual modelling tool to realize multi-dimensional visualization of the design and exchange of design data within the design team BIM and the other computer-based virtual modelling and analysis tools are used to simulate and predict design performance (Haymaker 2007). So what is BIM actually? BIM is a concept based on digitally performed, three-dimensional design modelling in which disciplinary design information is simultaneously 'articulated'. This articulation is through adding the design information in forms of visually modelled design objects (i.e. architectural, mechanical, structural sense) with the properties (i.e. quantities, types, and qualities of the objects). According to Eastman et al. (2008) and Spekkink et al. (2009), BIM is the most promising development in the design and construction industry and results in better quality, less costs and more benefit for clients and end users. Chao-Duivis (2009) draws attention to the easing character of BIM for externalizing responsibilities through the labelling of all data. BIM is discussed as an important supporting technology for integrated design approaches, in particular for both IPD and IDDS (Sebastian 2009; Churchill and Thoren, 2009; AIA, 2007; CIB, 2009).

The intended results of BIM are elaboration of the design product in a multidimensional (therefore multi-disciplinary) way in which all the relevant data and information can be visualized and embedded. One can claim that by promoting the use of BIM the externalization of the design information can be enhanced in a multi-disciplinary sense. BIM attempts to change the conventional design methods since the designers use the same digital environment and tools to conduct their design processes. Nevertheless, beyond being a design tool, BIM virtually creates a design space in which actors interact remotely. The interaction is through the externalized design objects in the virtual model. In order to talk about the synchronous and simultaneous design processes, BIM requires participation and commitment to a new digital collaborative design activity. The actors (in particular from different design domains) use their discipline-specific software applications. Schrama (2011) has remarked that the actual use of BIM in practice still appears to be challenging. Interoperability issues (data exchange between the software applications from different manufacturers) are difficult (Shen et al. 2009; Amor 2009; Farinha et al. 2007). Although, efforts have been made to solve the interoperability issues (i.e. the Industrial Foundation Classes (IFC)'s standard exchange languages) (Shen et al. 2009), as a result of the interoperability issues, the exchange of design information within the design teams remains limited, and somewhat frustrating (Issa, 2007). Moreover, the actors appear reluctant to use the integration of design information. This links us to the implementations on the managerial level, which may be resisted at the operational level, particularly if the approaches used target a structural change in the work methodologies.

BIM therefore requires a new way of collaborative designing even though it enables actors to work within their disciplinary island, but still with being aware of the other actors' design processes (since they are visually traceable within the digital model). This illustrates the importance of the willingness of people who actually 'detail the set vision' as Minztberg draws attention. In these approaches , we can see how people become important. This connects the discussion to the approaches that attempt to embrace the people using these tools and forming the social structure through which the tool use is embedded..

§ 2.4.7.2 People-oriented Approaches

It is increasingly acknowledged that besides technological development, aspects such as work processes, knowledge sharing and balanced teams of skilled professionals should be taken into account to improve performance (Rekola et al, 2009; Sebastian, 2009). In other words, the focus is shifting from a solely technology-oriented approach towards more organization and process-oriented approaches and increasingly on the social aspects of team collaboration. In people-focused strategies, creating, supporting, and enhancing CoP through digital technologies, the proximity and/or co-location of the design team (as bringing key actors physically together in the design process) all serve as examples.

Peansupap and Walker (2005) promote the principles CoP for facilitating ICT use for knowledge sharing. These principles serve to promote an open environment and informal interaction by designing an interaction format, built upon the organizational culture which respects the value of sharing, defines a joint-interest, embeds the knowledge-sharing practices into the work processes of the group, and creates an environment in which knowledge sharing is based upon processes and cultural norms defined by the community (Peansupap et al. 2005). Gupta and McDaniel (2002) propose five components for the effective management of knowledge:

1. harvesting (recognising and obtaining the knowledge from the individuals or groups)
2. filtering (using knowledge that produces a competitive advantage and discarding other knowledge)
3. configuration (as putting the knowledge in an readily understandable and useful way by organizing and storing it)
4. dissemination (communicating the knowledge or facilitating its use)
5. application (as applying the knowledge in everyday business activities) (Gupta et al. 2002)

However, these components refer to a simple continuum rather than a cycle, which requires learning and therefore sharing and integrating knowledge. Previously CoPs were discussed as the community perspective of management of knowledge approaches. The conclusion was that CoP emerges naturally within/across organizations. The work practices, the knowledge to be re-produced, the trust that enables the members to share openly and bond together are important.

There are various approaches to support CoP with digital technologies such as internet-based interaction applications to create electronic environments. These platforms have different purposes than the collaborative design tools that have been discussed in regard to technology-oriented approaches. Although CoP would be an ideal form of social structure for LCBPs, there is no specific approach for creating CoP at the project level. The reasons vary. Firstly, the intention to create a CoP potentially contradicts the emergent character of a CoP (as discussed previously, CoP may disappear when they are forced to function). Secondly, a CoP occurs naturally regardless of its being within organizations and projects. The members accumulate over time through the trust ensured. Argyris et al. (2006) analysed the CoP as institution-based and knowledge-based. In knowledge-based, the participants share their insights, knowledge once they gain trust to the others that their sharing will not be misused) (Argyris et al. 2006). As a strategic implementation for the project-level, forming a CoP across organizations for a temporary period becomes a challenge. Although CoP is a social structure and crucial, using solely CoP for knowledge sharing in the design process may remain limited due to the potential of collaborative design tools once they are aligned to the social structures of the projects.

As another example of people-oriented approaches, Mark (2002), Garcia et al. (2004) and Berends et al. (2006)discuss co-location of the design teams. Co-location is meant to create a physical environment in which key professionals from the organizations involved in the projects can be brought together (Kahn et al. 1997). Mark (2002) and Garcia et al. (2004) view co-location as a strategic approach for increasing collaboration, promoting knowledge sharing processes through balanced teams of skilled professionals. The actors are expected to collaborate, share insights due to the advantage of being in the same physical environment. However, such integrated and co-located work processes require different skills and knowledge of professionals as well as the different roles in the design team (CIB, 2009; AIA, 2007; Mark, 2002). In this way, the selection of the participants to serve on the co-located design team becomes important. In relationship with promoting knowledge sharing across actors, co-location emerges as a KSE in design teams. However, the selection of the physical location, the properties of the layouts, the participants, and the tools that support their interaction and design elaboration becomes important as well.

Kahn et al. (1997)'s research has been conducted in order to analyse the co-located design teams in a new product development context. They admit that co-location is a viable approach to enhance collaboration and communication through the physical interaction of the actors. Yet, implementing co-location still solely remains limited to knowledge sharing. In other words, even though co-location 'seems to be a good idea' because it creates a continuous design environment in which actors' practice two modes of knowledge sharing (active and passive), it requires additional components to succeed in knowledge sharing. Chachere et al. (2004) and Garcia et al. (2004) focus on tools as additional components with modelling and visualizations purposes. They perceive the tools as support for the concurrent collaboration between the co-located design team. Gorse et al. (2009) draw attention to temporal physical settings as these settings are important. Gorse et al. (2009) discuss meetings, as they are temporal but face-to-face interdisciplinary social interaction environments. They introduce meetings as essential mechanisms for sharing information and facilitating decisions. They simply note that creating the group environment can enable individuals to gather the relevant knowledge through individuals'' exchanged information and responses within the environment. They find these settings particularly important within a project environment that is perceived unique, temporary, and complex. In project environments, actors often find themselves being placed in new groups (i.e. working with others for the first time), thus the social interaction is crucial for developing work relationships. Although meetings are focused (since they are temporal, have agendas, and performed in a setting that is not a regular working space of the all participants), they create opportunities for people to boost their informal interaction during the breaks. Therefore, the members who are not active in the meetings can engage in social interaction and have a shared motives in the design process (Gorse et al. 2009).

Meetings are held in the nature of the design process and they are conventional efforts. However, organizing meetings does not solely represent a strategy to improve knowledge sharing practices, since the ways of producing the artefacts (not only validating and interpreting them in the meetings), interaction while designers involve in their disciplinary design processes are also important. This links us to the need of – either temporarily or long-term held- environment where actors are promoted to share knowledge with the support of tools.

One example of a tool-supported, temporary co-located environment is XC (eXtreme Collaboration). Albeit not in a building context, Mark (2002) studied XC in the projects within NASA. The collaboration through co-location takes place in an electronic and social environment, described as the "war room", which has the purpose of maximizing communication and information flow (Schrama, 2011). The war room is described as a room with technologies such as central displays and computers with databases, visualization programs, and networks. A design team works in a designed environment to develop designs for space missions. In relation to this idea, the Virtual Design and Construct (VDC) approach is discussed below.

Similar to both IPD and IDDS, VDC is referred to as an integrated design approach that is focused on increasing integration in the industry (Owen, 2009; Garcia et al, 2004; Kunz and Fischer, 2009). Kunz and Fischer (2009) combined their visions about the co-located method, tools, and the "war_room" with the VDC components. They discuss whether the co-location increases the focus of the design team members: clarify goals, methods, and shared-vocabulary. Because actors are physically in one room, goals, methods, and vocabulary are more explicit and understandable. Besides that, the waiting time for responses to questions and request for information is reduced (Kunz and Fischer, 2009).

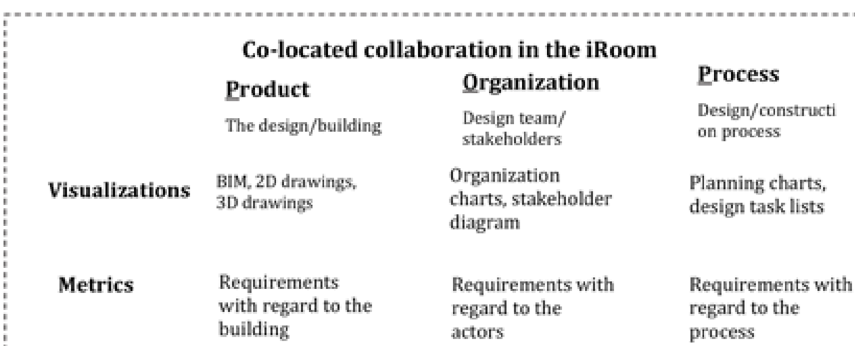

Figure 9
Virtual Design and Construct (VDC) approach and its components adapted from Schrama (2011)

VDC aims to improve multi-disciplinary design team collaboration by using visualization tools, performance-measuring tools at the levels of the design, and the co-location of the design team and the design process (Kunz and Fischer, 2009). One can argue that VDC is another form of the tool-oriented approach and perhaps it should have been discussed in the previous strategies. Yet, our choice of mentioning it here is the explicitness of the co-location included in the VDC approach. Whereas IPD and IDDS focus on the vision about integrated design, VDC is more focused on the operational aspects used to bring that vision to life. For example, VDC provides tools and suggestions, which can be used to reach design integration in the design process of projects. As such, VDC is an approach, which provides several steps, which can be taken in order to reach an integrated design process. The VDC approach consists of several components and their interrelation (see Figure 9). The visualization comprises illustration of Product, Organization, and Process (POP) and metrics refer to performance measurements of POP components.

However, VDC is still developing and the implementation of the VDC approach has only taken place within case study pilot environments in the US, performed by the developers of VDC. Insights into the implementation of VDC in real-life projects are scarce and companies struggle with the implementation of the VDC approach in their design process. Research has shown that the implementation of VDC is limited (Schrama, 2011). The case result of Schrama is that the VDC components have only been partially implemented. The co-location of actors is partial, but this supports the visualization of the conflicting interests and creates an awareness of the project schedule. However, the implementation of the metrics becomes problematic. Designers have trouble adjusting their work practices around the new models. In particular, LCBPs, the implementation of metrics challenged additionally since the metrics aimed to make the requirements and the design criteria explicit. Schrama (2011) discussed that VDC becomes a goal in itself, not a means to increase design coordination, externalization of ideas and keeping the track of design process.

§ 2.4.7.3 Reflections on Current Project-Specific Approaches

Above, two types of approaches were discussed in relation to their focus (tool and people) on promoting project-level knowledge sharing processes. However, three possible limitations have emerged.

1 *Broken link between contractual agreements and social bonds*
In the tool-oriented approaches, both the integrated project delivery approach IPD and IDDS were discussed as they combine different elements to create strategic attempts. These elements serve as technology, in the contractual settings for improved collaboration. The approaches are broadly set visions through introducing new business models (Schrama, 2011) and have two possible dangers. Firstly, top-down

introduced contractual 'bonds' do not mean that a social bond (as social infrastructure for knowledge sharing) is created. Secondly, by introducing new business models the actors may show reluctance on the operational level. It does not necessarily mean that actors are unwilling to use these models. However, actors may prefer to continue using their existing work methodologies with which they have been comfortable. The implementations mainly refer to a change in their work practices, yet when 'the work' is challenged by time pressure, the changing behaviours and using the new methods, may be seen as an auxiliary objective.

2 *Unbalanced emphasises between people and tool*

In both approaches, an unbalanced emphasis occurred regarding the two aspects: people and tools. The Virtual Design and Construct (VDC) approach attempts to blend the two aspects as presented by Khanzode et al. (2006). But Scharma (2011)'s research revealed that VDC is over detailed, and strictly predefines the steps people need to take, the tools they need to use, and the equipment in a co-located environment in which actors need to interact (including the agendas). The research done by Scharma (2011) has shown that VDC carried the danger of being too strict as potentially being a 'pre-manufactured' strategy.' The earlier implementations indicated that attention was placed upon the implementation of product visualizations and the use of BIM during a project (Garcia et al, 2004; Khanzode et al, 2008) and these implementations have already become immature (Garcia et al. 2004; Schrama, 2011). The highly prescriptive nature of VDC constrains the project actors from embedding the VDC to the current organizational processes (as they attempt to shift the design process radically) and integrating it to their current design practices. The findings of the real-life cases represented that the actors, in particular, were architects challenged when using the prescribed systems implementation of the complete VDC approach, which remains superficial, if not impossible. Its elements only implemented partially by the actors who both initiated VDC and participated. This demonstrates the danger of VDC as being perceived as one solution for all the projects. Dixon (2000) sees this as a potential for failure when organizations insist on a 'one-size-fits-all' approach for knowledge management problems. One can assume that VDC represents an imposed strategy when it is imported and developed from a different context. However, its applications need to be considered carefully by understanding the current variety of the organizational design processes and it needs to be adapted to LCBPs. Furthermore, there are currently discussions on legal issues that comes along with BIM implementations. These issues are such as ownerships of data sets, ownership of intellectual knowledge, and ownership of the model itself. Furthermore, there are currently discussions on legal issues that come along with BIM implementations. These issues include ownerships of data sets, ownership of intellectual knowledge, and ownership of the model itself. They are also associated with BIM related roles, responsibilities and tasks. The BIM associated roles and the legal issues require clarification and agreement between parties about BIM implementations. This challenges project actors to integrate this concept to their existing design practices. Currently, there is not legal instrument available to deal with the consequences of BIM implementations in relation with these issues.

3 *Limited responsive environments for knowledge sharing processes*

As defined in § 2.4.6, the responsive environment undeniably becomes important in knowledge sharing processes among actors. In the case of creating or promoting CoPs, digital interaction platforms served as examples for responsive environments tools. There are more particular tools required to support their naturally occurring knowledge sharing behaviours. In the VDC approach, physical settings (war rooms, iRooms, etc.) become a way to create responsive environments. BIM represented a digital environment. Nevertheless, realizing and creating such environments (either tool-supported or physical) cause the implementers to overlook the actual performance of responsive environments. VDC resulted in asking compulsory attendance that has a danger in diminishing the motivation of actors to participate in such environments, whereas BIM has a danger that implementers focus on working in BIM without actually reviewing whether the goals have been achieved.

None of the project-level strategies targeted -specifically- promoting knowledge sharing processes among design team organizations in the on-going projects. Project delivery methods (IPD and IDDS) are more high-level discussions and their implementations suggest the use of digital technologies, but without supplying the footsteps to actually implement with regard to people in projects. Thus, CoPs are not implemented strategically in any project-level settings. In the case of LCBPs, CoP members are often too unfamiliar with one another due to the division of labour to react to each other's boundary objects and to share knowledge naturally. CoPs are organically grown groups; establishing them as a top-down effort may inhibit their sharing activities.

BIM is only a digital design information-integration tool around which there are regulations and motivations. BIM represented an interactive tool component around which social interactions still needs to be planned. BIM itself did not represent a strategy for LCBPs, not a strategy in itself. Similarly, co-location (in particular short-time implementations such as regular meetings) is only a component of a KSS, when implemented solely. The contractual project delivery models such as IPD, IDDS, and also VDC aim at collaboration and improving project performances. None of the approaches are literally conceptualized as KSS for LCBPs. It is naive to assume that the contractual agreements (even though the collaboration is highly promoted in managerial levels) will naturally create a sharing social structure with the alignment of tools. Since projects provide 'new' situations in which the participants are often unfamiliar with each other, special attention is needed in order to increase the social bonds between them. Solely introduced top-level agreements may remain limited in creating a social bond, which would cultivate the use of tools. The broad message here is that designing strategies requires that attention be paid to the social aspects in order to realize the intentions set by organizations that should be realized in the operational level. This needs a careful design and an implementation strategy.

In this section, I examined whether current approaches refer to knowledge sharing strategies for LCBPs. The project-specific approaches established a link to the characteristics of large complex building projects (highlighted in § 2.4.1) which seemingly become potential challenges against knowledge sharing approaches for large complex building projects.

§ 2.4.7.4 The Challenges of Project-Specific to be Knowledge Sharing Approaches

Large complex building projects present particular challenges for designing and implementing project-specific knowledge sharing approaches. Through reviewing the existing approaches dealing with the design process and design knowledge, the nature of large complex building projects, being unique temporary and complex settings, represented to be three challenges against designing and implementing project-specific knowledge sharing approaches for large complex building projects.

Firstly, large complex building projects are unique (DeFilippi et al. 1998; Fredrickson 1998; Grabher 2002; Turner et al. 2003; Jashapara 2004; Bresnen 2007) in terms of design and construction (Fong 2003). They have a unique mix of different ingredients such as relationships, but these are often overlooked (Pryke et al. 2006). While Fredrickson (1998) claims that there is no 'one fits all' solution for each project (Fredrickson 1998), Grabher (2002) argues that projects carry similar design methodologies. The review in Section 2.4.7.3 portrayed that the current approaches do not pay sufficient attention to deal with the unique features of a project, particularly little emphasis on forming relationships between the project actors that uniquely form the project team and project culture. They also do not clearly identify the generic issues in these projects. Therefore, the uniqueness of a project presented a challenge to establish a knowledge sharing strategy that deals with knowledge sharing but also with own project-specific dynamics, requirements, land, and organizations collaborating to achieve a project.

Secondly, temporariness becomes a potential challenge to creating social structure with a 'sharing culture' within projects. Projects are temporary and inter-organizational relations in and across this temporariness seem to have been neglected (Soder-Lund and Andersson 1998). Projects accommodate permanent systems, for example organizations who deliver services through the projects they are temporarily involved in (Grabher 2002). Normally, social structures emerge naturally as a result of repeated interactions between actors. Yet, in large complex building projects the social structures are complex due to the involvement of multiple organizations and interactions are limited, which lead to the challenges of inter-organizational coordination (Barlow 2000; Jones et al. 2008). There are only a few studies on how multiple actors coordinate their collaborative efforts and how the expectation of limited duration shapes and modifies their interactions (Jones et al. 2008).

The third challenge observed is the complexity of the large complex building projects. Organizations are socially complex arrangements consisting of relationships and interactions involving individuals and groups with diverse mind-sets and interests (Bresnen et al. 2005). In their book of 'harnessing the complexity', Axelrod et al. (2000) addresses the complexity of a system in which strong interrelations among its elements are required and any changes in the elements influences the overall system. Axelrod et al. (2000) claims that when a system contains 'agents' and 'populations' that seek to adapt, it becomes a Complex Adaptive System. When a system contains agents and/or puplations that seek to adop, it refers Complex Adaptive Systems (Axelrod et al. 2000). They claim agent as a person or a team member who has an ability to interact with its environment and can respondto what happens around. The population consists of agents and a source of knowledge, recipents for a newfound imporvement and a way to spread learning (Axelrod et al. 2000). This view positiones people in the center of an approach and uses the groups who are socially connected as an engine to stimulate knowledge sharing and spread learning. It is also clesely linked to the concept of Communities of Practice. By following their thought, the design teams of large complex presents a potential complex adaptive systems. However, their varying types of practices, relationships, and interactions affect the manageability of the complexity of projects. Williams (1999) characterizes the complexity with different dimensions of uncertainty; structural uncertainty (consisting of number of elements and their interdependency) and uncertainty (in goals and methods) and claims that when there is a reduction or additional extras in the functionalities of the 'end-product' that project delivers. This emphasizes the changes in the process of a project. The organizational, structural, and technical complexity leaves little room to the project actors to develop project-specific strategies dealing knowledge sharing in such projects.

These three challenges associated with the nature of large complex building projects need more emphasis to be investigated. These challenges need to be understood as understanding those help us to know the playground of project actors where the nature of the design process held by the designers, the process of sharing design knowledge is conducted. Then the strategies dealing with knowledge sharing within unique, temporary, and complex settings can be more targeted, as these strategies can deal with the project-specific issues. The project-specific strategies are called Knowledge Sharing Strategies.

§ 2.4.7.5 The Necessity of a Holistic Framework for Knowledge Sharing Strategies for Large Complex Building Projects

In this research, Knowledge sharing strategies (KSS) refer to sets of implementations planned to facilitate externalization and socialization processes in and between actors who conduct and evolve their organizational practices, who improve access to information, who ease the communication between the actors, and who encourage participation in learning which is sustained by knowledge sharing. In the design teams of LCBPs, KSS are planned approaches used to tackle knowledge sharing processes among different organizations in both remote and proximate manners. By carefully planning these approaches and operationalizing these intentions, boundaries are crossed; knowledge is generated, shared, and then integrated. By doing so, actors achieve a collective learning process in projects. Through the approaches organized around the vehicles, different perspectives of actors made evident, the documentation and exchange of objects are done systematically, relationships between the actors can be enhanced, an open and motivating working environment (both remote and proximate) is achieved.

The reflections presented in § 2.4.7.3 and the challenges presented in § 2.4.7.4 emphasized the need for a holistic approach that can be used for designing and implementing operations that promotes knowledge sharing processes throughout the design process within unique, temporary, and complex settings of large complex building projects. In other words, it became evident that current project-specific approaches do individually deal with different aspects of knowledge sharing such as procedures (through new contractual agreements), tools and technologies that focus on distant communication, interaction and virtual designing, and partially consider the benefit of face-to-face interactions and physical settings (i.e. war rooms, Irooms, etc.). There is a need for a holistic framework of knowledge sharing strategies that synthesizes the aspects of knowledge sharing within large complex building projects. The framework needs to have two dimensions;

1. a managerial dimension in terms of the strategic aspects that are necessary to manage the way a knowledge sharing strategy is enacted as a holistic approach,
2. a contextual dimension in order to clarify the content of a knowledge sharing strategy, identifying and interrelating the operations to promote knowledge sharing

§ 2.4.8 Knowledge Sharing Strategies for Large Complex Building Projects

In this research, Knowledge sharing strategies (KSS) refer to sets of implementations planned to facilitate externalization and socialization processes in and between actors who conduct and evolve their organizational practices, who improve access to information, who ease the communication between the actors, and who encourage participation in learning which is sustained by knowledge sharing. In the design teams of LCBPs, KSS are planned approaches used to tackle knowledge sharing processes among different organizations in both remote and proximate manners. These approaches should have technological, social, technological, and procedural dimensions. In this study, KSS is a phenomenon to be investigated. KSS does not represent either a theoretical or a strategic model itself. KSS is a concept that has been introduced due to the research gaps in this study. In order to analyse the two case studies and their extent of KSS, a holistic framework is needed. This framework for KSS requires strategic concepts contextualized to LCBPs and a suitable theory in which this specific research study can be positioned. The following section explores the strategic concepts and introduces a suitable theory in order to build a holistic framework of KSS for LCBPs.

§ 2.5 A Holistic Framework of Knowledge Sharing Strategies for Large Complex Building Projects

Building on the review of the literature, this section proposes an analytical framework for knowledge sharing strategies that synthesizes strategic and theoretical dimensions in a holistic manner. For the strategic dimension, Mintzberg's (1973) work on strategy is used as a basis. For the components of a KSS, Activity Theory forms the theoretical basis for conceptualising work in complex settings.

§ 2.5.1 The Managerial Dimension of KSS: Intended, Emergent and Realized Strategies

A leading scholar on strategy, Mintzberg (Mintzberg 1973) defined strategy as a 'pattern in a stream of decisions'. He approaches strategies as deliberately planned acts and intentions to either change or pursue the current situation. In his more recent work, Mintzberg (2005) avoids a single definition and provides four definitions of strategy as 1) 'sets of directions', 2) 'focusing on efforts', 3) 'defining organization', and 4) 'providing consistency'. These four definitions should refer to a continuum for the implementations of a strategy. The general advantage of a strategy is that it can provide an indication of which path people should pursue in order to work on the details, but this path may not function fully due to how people will react along this path. Mintzberg et al. (2005) use a metaphor to explain this: a ship is sailing along the path but it crashes into an iceberg in unknown water. The ship and iceberg metaphor illustrates the predetermined course of actions that needs to be applied slowly by considering the feedback to be applied to the strategies. In other words, without a strategy focusing on efforts, a chaotic environment can occur as well as it stimulating both feedback and emergent efforts in the environment in which the strategy has been implemented. Since predetermined sets of actions may not fully work in unforeseen future conditions, opportunities can be missed due to the clear direction and/or the people who are challenged by the unknown or ambiguous conditions that have been disabled in order to create innovative solutions. This carries the danger of overlooking the emerging strategies that arise when the participants must tackle conditions that they have not anticipated or they did not intend to solve initially.

The different perceptions of strategies link us to the intention and consequences of strategies. The types of strategies are intended, deliberate, unrealized, emerging, and realized (Mintzberg et al. 1985; Mintzberg et al. 1988; Mintzberg et al. 2005). Figure 10 illustrates the concepts of a strategy as intended, deliberate and realized as well as an unrealized strategy as the failing parts and emergent strategy that pop up in the process of the implementing of a strategy.

Intended strategy is planned to target the desired achievement. The intended strategy has three conditions; 1) deliberate intentions articulated in detailed level of actions (a clear intention about what was desired), 2) a common collective agreement about the intentions and 3) precise achievements to the desired level (Mintzberg et al. 1985). Their discussion draws attention to the fact that there can be pure neither intended nor pure emerging strategies.

Firstly, the organizations may not be aware of the desired achievement that can evolve throughout the process of actions implemented within the strategies. Secondly, the collective actions may not be fulfilled completely due to the changing external factors (i.e. market conditions etc.). Consequently, another version of the intended achievement can be realized. An intended strategy becomes a deliberate strategy, when operations and actions are realized.

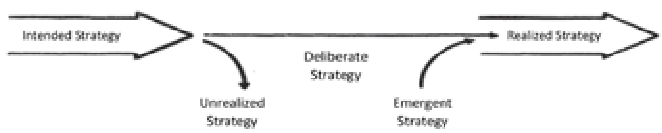

Figure 10
The types of strategies according to Mintzberg et al. (1985)

Emergent strategy is a strategy that is enacted without clear or explicit intentions. In the pure emergent notion, there must be a total absence of intention, which is difficult to imagine (Mintzberg et al. 1985). It is characteristic of emergent strategies that intention emerges at one point and the actions are planned based on how that intention emerges. Unlike the deliberate strategy, the intention may not coexist earlier, but it emerges. This is the discrepancy between intended and emerging strategies.

As illustrated in Figure 10, there is a continuum starting from the intention to the realization. This continual process can be accommodated by unrealized or failed strategies as well as emerging strategies that have arisen throughout the process and which were not foreseen and intended before the actions taken. When understanding the types of strategies it is important to be aware of the planning of actions as forming the strategies, but one should also consider the potential acts that emerge in the process of any activity.

The probability of purely planned or purely emergent strategies is low according to Mintzberg (1973). All types of strategies are under the influence of external (i.e. clients) and internal factors (the individuals, work groups engaged in the strategies). Mintzberg and Waters (1985) note that understating the different types of strategies and how they blend into each other becomes important for designing and implementing a strategy. They add that emergent does not mean chaos, but unintended order and in some cases, it is open and responsive. Similarly, they do not claim that deliberate strategies are dysfunctional; managers need to implement formal sets of actions, and sometimes they impose their intentions on the work environment. Mintzberg and Waters (1985) draw attention to the blend of both emergent and deliberate strategies, which are unrelated to their categories stated above. The important point is that emergent strategies enable managers to handle the situations that they cannot be close enough to. Emergent strategies refer to more collective action arising from the needs in the work environment, whereas deliberate strategies emphasize the central direction and hierarchy.

Figure 11 illustrates the learning loop that gathers feedback from people on the differences between intended strategy and realized strategy. This loop includes the reasons of having unrealized components of a strategy (if not the whole strategy) and the types and motivations behind emergent strategies (if occur). This loop becomes important in order to understand the conditions for which category is appropriate for the intended aims.

Up until now, the discussions of the strategies pointed out an overall relationship between intentions, (un)realizations and emergences without going into the implementation details for knowledge sharing processes among actors in LCBPs. The emerging question is, how can a strategy for regulating the knowledge sharing processes of actors in LCBPs be planned in order to achieve the proposed goals that may evolve throughout the process? In addition to this question, it becomes important to know "how do practitioners approach planning a strategy which embraces the emerging efforts in which a strategy is formed naturally to achieve a goal?

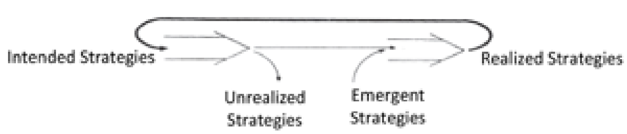

Figure 11
Mintzberg's strategic learning loop (Mintzberg et al. 1985)

Becker (2001) introduces four types of strategies that tackle dispersed knowledge for a project setting. They are 1) 'creating information processing channels' (referring to enhancing social relationships), 2) 'recreating missing components' in the settings (referring to subconscious strategies that are seemingly similar to emergent strategies),' 3) improving coordination mechanisms' (referring to enhancing informal coordination i.e. CoP), 4) 'decomposition' (decomposing large tasks and units into smaller ones to improve reduce the opaqueness and improve the interaction). He notes that the usefulness of strategies may change over time and that changes in the environment can require adjustment. This overlaps with Mintzberg's position (Mintzberg et al. 1985; Mintzberg et al. 2005) on the importance of embracing emerging strategies as well as being aware of the deliberate strategies, whether or not they target the goals. Becker (2001) introduces accessing knowledge through designing information channels and emphasizes that a knowledge sharing strategy requires a set of different ones. Becker's findings overlap with the concepts of Mintzberg as differing from embracing emergent strategies to strictly following the deliberate strategies. Although Becker (2001) literally uses the term of 'knowledge sharing strategies', he does not specifically focus on KSS for projects and certainly not for LCBPs. The strategies he pays attention to do not fulfil the requirements for knowledge sharing among the different actors at the project level.

Intended KSS starts with Intentions that attempt to deal with facilitating knowledge sharing across organizations, therefore contains motivations of actors towards inter-organizational Implementations. Implementations are operations that deal with the key aspects of a KSS such as tools, people engaging in knowledge sharing practices and rules. Therefore, implementations target the mechanisms of knowledge sharing and attempt to create a Knowledge Sharing Environment (KSE) in the LCBP . Since not all implementations succeed in ensuring knowledge sharing between actors, implementations can result in both realized and unrealized components in the project environment. Unrealized components are the intentions that are not achieved within the overall strategy. These occur, for instance, when implementations fail to realize the intentions. Unrealized components can, for example, occur as a result of a mismatch in the ways that design teams enact the intentions of implementers (i.e. client team organizations, project managers, design leaders, etc.).

Even though LCPB project environments have an intended KSS that leads people to a deliberate KSS, emergent strategies can occur. In the context of KSS for LCBPs, emergent strategies represent efforts that deal with one or more aspects of KSS. These strategies are the result of particular actors' efforts that have been initiated in order to tackle challenges within the design process. Emergent strategies can also be local practices that are designed to deal with unrealized components of an intended KSS, for example, a patch for missing components of an intended KSS. Therefore, in Figure 12 the category 'potentials' has been added. This category represents the emergent strategies that fulfil the aspects of a KSS for LCBPs.

A ‘Realized KSS’ is the result of both the intended and emergent strategies. In the end, intended KSS result in a realized KSS (that reveals both the extent of achievements comprising the differences and/or overlaps between intentions and realizations) and (potentially) unfulfilled intentions.

When analysing the cases, both emergent strategies that have the potential of becoming either partial or full KSS and/or deliberate strategies (based on the intended strategies) are taken into consideration to represent the current extent of KSS for LCBPs.

In order to analyse the realized, unrealized components of a deliberate KSS and detect whether there are emergent KSS, there is a suitable theoretical framework needed. This theoretical framework enables to discuss the implementations that tackle knowledge sharing in a holistic manner in addition to the strategic framework proposed in Figure 12. Therefore, Activity Theory is selected.

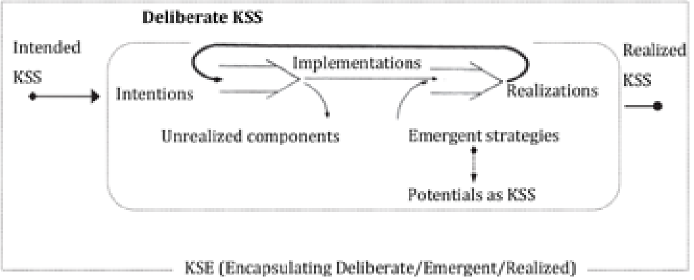

Figure 12
Categories and their components used for conceptualizing KSS for LCBPs that will be used for evaluating the strategies

§ 2.5.2 The Contectual Dimension of Knowledge Sharing Strategies: Activity Theory

This section argues why Activity Theory (AT) is suitable as a theoretical framework for investigating knowledge sharing strategies for LCBPs and outlines the components of AT. As previously stated in the limitations of current knowledge sharing approaches (see § 2.4.7.4), the existing literature on the management of knowledge does not seem adequate in addressing the considerable complexity and the challenges of knowledge integration process in team settings (Alavi et al. 2002). The traditional frameworks separate the study of socio-economic structures from the study of individual behaviour and human agency. In these theories, the individual as an acting subject who learns and develops does not seem to influence the surrounding structures (Engeström 1999). Thus, there is a limited amount of theoretical frameworks that view knowledge sharing as an individual and social activity, mediated by tools and artefacts in the unique, temporary, and complex design teams. But why is Activity Theory then suitable for KSS?

Two Russian psychologists Vygotsky (1978) and Leont 'ev (1978) initiated Activity Theory in the 1920s and 1930s. Activity theory is now a global multidisciplinary research approach (Engeström et al. 1998, Chaiklin et al. 1999) that is oriented toward the study of work and technologies (Nardi 1996). Senge (1997) define AT as a socio-cultural, socio-historical lens through which designers can analyse human activity systems.

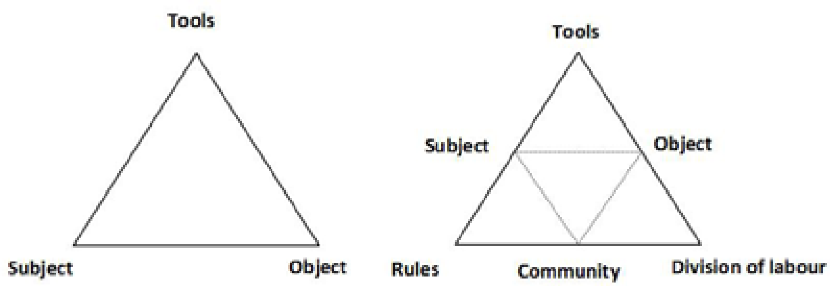

Figure 13
a the early version of the AT model, b the elaborated version of AT and mediated relationships according to (Engeström 1999)

AT has six components: the subject, tools, object, rules, community, and division of labour (see Figure 13a and b). Put simply, AT proposes that people (the subject) engage in an activity directed at the object and that this activity is mediated by the tools being used (see Figure 13a). In Engeström's more elaborate version of the model, this activity is also socially mediated through the rules that regulate what counts as acceptable, (professional) community that people belong to, and the division of labour. Thus, subject produces either an object that is defined by sub-tasks through division of labour or a main object that integrates all the sub-tasks accomplished through division of labour.

The main tenets of Activity Theory are a) consciousness, b) the asymmetrical relation between people and things, and c) the role of artefacts (Kazi 2005). AT incorporates the strong notions of intentionality, history, mediation, collaboration and development in constructing consciousness (Kazi 2005). It has been used as a framework to analyse the interactions, object and activities to be held in learning environments (Blackler 1995; Senge 1997; Skyrme et al. 1997; Engeström et al. 2005). Brown and Duguid (Brown et al. 2001) claim that AT can offer a framework for the researcher regarding distributed communities where work and learning are barely distinguishable. Senge (1997) propose AT as a clear operational framework for designing a learning environment. Mertins et al. (2001) claims that collaborative working groups are learning communities that experientially, tacitly, constructively, and contextually grow. Hence, AT represents a possible conceptual framework for the design environment of large complex building projects.

When analysing human activity, not only the kinds of activities that people engage in should be examined, but also those who engage in that activity. The goals and the intentions of people, the kinds of objects or products that result from the activity, the rules and norms that circumscribe that activity, and the larger community in which the activity occurs as these are all parts of the activity system and these parts need to be known (Senge 1997). Grant (1996) notes that rules facilitate social interaction and can provide a mean by which tacit knowledge can be converted to explicit knowledge, as the rules establishes a ground to clarify activities. This results in a shared practice that connects "knowing" with "doing" Maaninen-Olsson et al. (2008) and Wismén et al. (2006). And 'what you do' is embedded in the social matrix of which every person is an organic part and composed of people and artefacts (tools, signs, language) (Kazi 2005). Practices are always the product of specific historical conditions that result from previous practice and are transformed into present practice (Gherardi 2000).

AT enables us to examine current design practices within a project environment of a LCBP involving in the design activity within either loose or a rigid context defined by the client and design team. Throughout this activity, actors (i.e. designers and managers of the design team organizations and client representatives) attempt to align their intentions and integrate design objects (artefacts) they produce. The design activity does not only refer to individual intentions and artefact production, but to the wider community that actors belong to (such as their permanent organizations and the design team of the project). The design team and the client as a wider community include goals (organizational objectives to be achieved in a project setting), norms (as acceptance of their organizational practices), and legal and functional rules among the different communities (contractual relationships, communication or interaction procedures, production or tool-use rules in a project setting) and their reflection onto the design activity. The dynamic process between designers and managers of the design team mediated by tools and regulated by the rules and norms of both client and organizations involved in producing the object (integrating the divided disciplinary tasks and the solutions) result in a shared practice in LCBPs.

In this study, AT is proposed as a suitable theoretical lens for analysing the social and remote knowledge sharing processes of actors through understanding the interactions of different work groups (performed by individuals) in LCBPs. For examining the phenomenon of KSS for LCBPs, I focus on three aspects of AT that were found to be most relevant for the context of this study. Those that remained constant in LCBPs were not used as analytical categories in this research, namely the object, the division of work and the subjects. By focusing on LCBP, the object as such as given. In all projects, the division of work had already been arranged. These constants are also the existing motives of organizations to engage in inter-organizational activities, while organizations coordinate their design activities around the division of the work, integrate different solutions in order to accomplish the main design object. The designers and managers are appointed to realize their particular tasks, and the division of labour in LCBPs becomes the connection among the actors.

Regarding the actors or subject in KSS, and our analysis focused on social practices rather than individual motivations. In the design process of LCBPs, actors are professionals who represent their organization in the design team. The design team comprises varied organizations, whose cultures and rules jointly constitute the community. While the individual members of the design team may change throughout the project, the social practices of knowledge sharing generally survive these fluctuations.

In the cases of LCBPs, the community can be considered as the design team, in their division of labour is legally interconnected by contractual arrangements. That means organizations legally promise to share their knowledge by means of producing boundary objects that are to fill the parts of the big project tasks. It is their responsibility to create a multi-disciplinary knowledge product as design. Throughout the project, the network of professionals grows closer, either starting from scratch with no one knowing each other or with a subgroup of people who are already familiar with one another. So the subject and community components of AT cover the aspects of social practices (see § 2.3.2).

Tools in AT enable actors to visualise objects and interact with each other. In KSS, tools are positioned as they have central roles to support distant and social processes of knowledge sharing as tools mediate interaction, externalization of (and accessing then retrieving) the knowledge of actors.

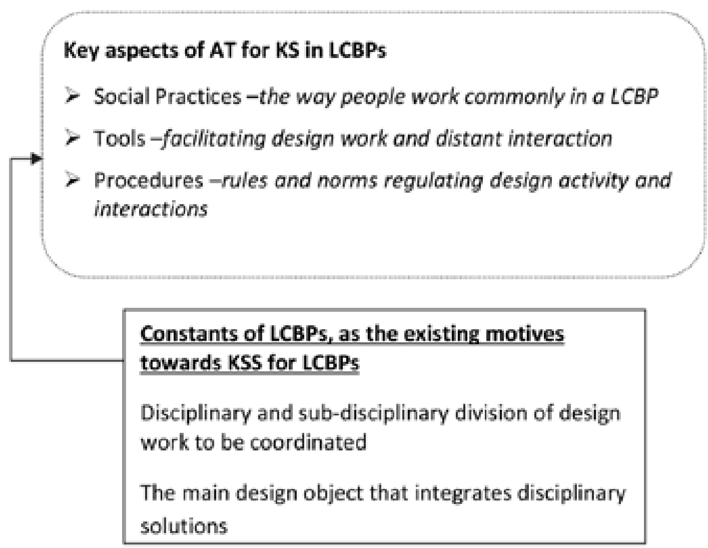

Figure 14
Components of Activity Theory considered in the analysis of KSS for LCBPs

Similar to tools, the aspect concerning rules in AT plays also an important role in KSS. The concept of rules in AT comprises a mixture of routines and regulations that a community regards as appropriate. In KSS for LCBPs, there are also procedures that regulate the exchange between actors and formalise how design teams should share knowledge. Procedures formulate the use of tools, define the boundaries to be crossed, and they determine the form of design objects to be produced and to be exchanged. These three main features, social practices, tools and rules, have been used to analyse current KSS for LCBPs (see Figure 14).

§ 2.5.3 The Knowledge Diamond as a Holistic Framework for Knowledge Sharing Strategies for Large Complex Building Projects

When synthesized with the key aspects of KSS for LCBPs through AT, the interrelation between the key aspects of KS (see Figure 14) has resulted in an analytical framework for KSS which is termed the 'Knowledge Diamond', as illustrated in Figure 15.

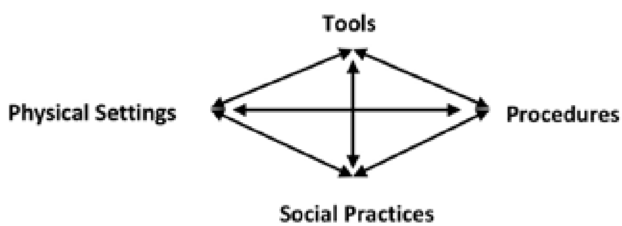

Figure 15
Four dimensions of KSS for LCBPs (based on the Activity Theory)

The Knowledge Diamond framework comprises four interconnected dimensions for analysing KSS for LCBPs: Tools, Procedures, Social practices, and Physical settings. The three of these dimensions are adopted from the Activity Theory. However, with regard to the knowledge sharing, the Activity Theory does not include and specify any physical environment. As reviewed in § 2.4.6, these environments are crucial for knowledge sharing. Therefore, in this knowledge diamond, a special attention is paid to these environments and the fourth dimension is defined as physical settings. These four dimensions produce a more compact and specialized version of the AT model focussing on the phenomenon that this study deals with. Any KSS should encompass implementations that encompass these four dimensions.

Tools is the first dimension of the Knowledge Diamond, as explained in § 2.3.1 and § 2.4.5.1.Tools refer to design specific models and methods that support knowledge sharing activities. Through this model, two cases will be analysed to see the way that tools facilitated actors in LCBPs, based on the review done in § 2.4.7. The analysis of tools in two cases will provide understanding on provision of virtual space for co-design activities (BIM, 3D-models), ease of social interaction between distant environments, capturing the decisions taken in the projects (via repositories) and explicit knowledge to be retrieved by the actors (via KMS, intranets etc.). In the analysis of two cases based on the Knowledge Diamond, the nature of the strategies implemented (deliberate or emergent); the (un) realized intentions will be explored through the implementations of actors towards tools.

The second dimension is 'Procedures'. In AT terms, this dimension synthesizes 'rules', and 'division of work'. In the context of KSS, procedures are contextualized as rules and norms that regulate knowledge sharing processes in LCBPs. In both tool and people oriented approaches, rules were the key concern. In IPD, IDDS and VDC, procedures were used to model the design process and various business processes of organizations involved in projects (see § 2.4.7). In CoP, procedures emerged as a critical issue that remained challenging to bond informally and naturally occurred knowledge sharing groups. Since KSS is targeted at inter-organizational knowledge sharing processes in LCBPs, procedures become an important dimension for defining the sharing code of actors when they cross their boundaries. Due to the complex social nature of design teams of LCBPs (as explained in § 2.4), it is necessary to clarify the sharing codes for actors. The code of sharing defines and regulates knowledge sharing space for actors. In the analysis of cases, procedure dimension will deal with exploring explicitly set rules and norms and implicitly shared routines in LCBPs. Both types refer to sets of principles regulating the way that design team organizations enact strategies. Explicit rules refer to formal interaction codes, schedules, the use of tools as well as contracts, and they can formalize design representation, exchange design information, interpret design information, and participate in the design team organizations. Implicit rules refer to the shared-routines of people regarding knowledge sharing processes. Design team members may not be fully aware of the types of rules they follow. Yet, these rules are important for portraying current practices and interaction habits of design teams so that any limitations and strengths of the design team can be compared with pure tool-oriented implementations. The division of work is necessitated by the size of LCBPs and results in a fragmented design task with knowledge domains represented by various design organizations. This division is regulated by contractual agreements between design organizations and the client. In other words, the division of work is encapsulated in rules. Beside the explicit and implicit rules of knowledge sharing of actors, the procedures dimension of the Knowledge Diamond will enable us to report the degree of the regulated design and implementations of the strategies implemented in two cases. Furthermore, the analysis will contain the way that emergent strategies are incorporated with the intended strategies.

The third dimension of the Knowledge Diamond is called "Social Practices'. It embraces the social and community aspects of AT. Individuals are part of the 'community' that refers to the total project team formed by both design and client teams. Social practices refers to a social structure that resembles a project-based CoP in which boundary crossing activities are promoted (including exchanging information, interacting informally and formally, and collaboratively interpreting design information). In social practices, actors from the three different levels can engage in design dialogues social interactions where knowledge is shared and the discussion of artefacts. The three levels are as 1) individuals who generate knowledge, apply this to their works, and visualize objects, 2) design crews that perform both personal and collaborative knowledge sharing processes, and 3) design team in which managerial and operational level actors contribute to multidisciplinary knowledge. People in the three levels engage in different social practices, as they hold and carry different both organizational and disciplinary perspectives, agendas and methodologies and hierarchical positions.

In the analysis of two cases, current social practices of people performed in all of the three levels will be reported; The social practices dimension of the Knowledge Diamond will enable us to report how people commonly work together on a project and engage in a project culture that has evolved in an organisation and perform implementations imposed by the strategies implemented in two cases. Thus, analysing social practices will report the way that both intended KSS and emergent KSS (if exists) are enacted by people regarding other dimensions of the Knowledge Diamond.

The fourth dimension of the Knowledge Diamond is Physical Settings. As indicated earlier, this dimension is not specifically addressed in AT and no special attention was paid in the AT, but emerged as an important component through the review of knowledge sharing (see § 2.4.6). In the literature review, the physical settings were noted as serving as a focal point for people-oriented strategies as they bring physical proximity to people and offer chance to engage in both social mechanisms of knowledge sharing. As an example, Savanovic et al. (2007); Savanovic (2009), and Quanjel (2013) established their approach based on the benefits of creating a series of workshop where cross-disciplinary teams externalize their knowledge and integrate it through using the benefits of face-to-face conversations and reciprocal design dialogues. These settings play a crucial role in cultivating knowledge sharing. Physical settings are also important as they capture the displacement of encounter to the virtual, including the dissonance of being virtually with someone while both parties are in their home territories. The physical settings dimension of the Knowledge Diamond will enable us to report way that physical settings contribute to boundary crossing activities (see § 2.3.2) by people participating to these settings. Furthermore, the analysis of the two cases will explore the relation between intended, emergent strategies with the physical settings, as it will explore whether the strategies incorporate physical settings.

In order to analyse KSSs in two cases, the Knowledge Diamond framework is incorporated with the strategic framework built upon the concepts of Henry Mintzberg (see Figure 16). This enables a holistic framework that comprises both the strategic implementations and the way that the implementations are enacted. Since knowledge is often intangible and difficult to measure, the implementations need to target these four dimensions and their interrelations to promote the conditions necessary for knowledge sharing processes among actors in LCBPs to take place. The arrows between the four dimensions refer to the necessity of the interrelations.

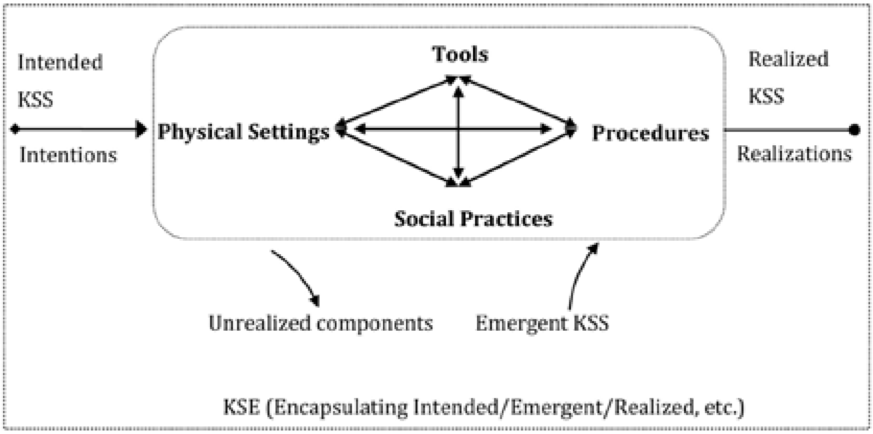

Figure 16
Holistic framework to analyse KSS and its components in LCBPs

§ 2.6 Concluding Remarks

This chapter clarified four issues. Firstly, definition of knowledge in both organizational and inter-organizational contexts and the way that knowledge is shared in both contexts were reviewed; this was done by examining the knowledge management and the organizational learning fields. The distinction between data, information, and knowledge was clarified. In this research, knowledge was addressed as a dynamic and organically growing asset that comprises based on contextual data and/or information exchanged, the values and insights gained through the previous experiences. Based on this organic nature, knowledge sharing was stressed as occurring in social (by and remote processes that connected the management of organizational knowledge.

Secondly, the two perspectives on management of knowledge, object and community-oriented, were reviewed and their shortcomings were reported. In the content perspective, technology was elaborated as a medium of knowledge sharing which presented neglecting people and their social processes, difficulty of dealing with tacit knowledge and slow adaptation of implementations by current design practices as its shortcomings. In the community perspective, the promising nature of the CoP was presented, as it referred to a knowledge sharing group of people. Their natural and informal formation of CoP, which resulted in largely independent and unconnected groups, reluctance against hierarchical implementation was found the shortcomings of the community perspective.

Thirdly, knowledge sharing among organization within LCBPs was contextualized and current project-specific approaches dealing with knowledge sharing were discussed. The relation between people, the artefacts embedding design information, tools and technologies, actions and social interactions with sharing design knowledge in LCBPS was addressed. Following this relation, two perspectives in current project-specific approaches that tackled knowledge sharing among different organizations were explored. BIM was reviewed as tool-oriented approach, whereas CoP and Co-location were found as people-oriented approach. Through reviewing their shortcomings, it was found that there was no clear definition of a Knowledge Sharing Strategy (KSS) for LCBPs. Thus, a clear definition of a KSS for LCBPs was done. Following to this definition, the necessity of a holistic framework (to not only analyse existing KSS but also to design and implement KSS for LCBPs) emerged. This led to the fourth and last issue; building a holistic framework of KSS for LCBPs.

Fourthly, a holistic framework for KSS in LCBPs was defined based upon the literature reviews done up until now. Firstly, the strategic dimension of the framework was added through synthesising the concepts of Mintzberg (1973) such as intended, (un)realized and emergent strategies. Secondly, the theoretical dimension of the framework was added. Activity Theory was presented as a suitable theoretical lens that can embed in the holistic framework and be synthesized with the strategic dimension. The six aspects of Activity Theory were redacted to four while contextualizing Activity Theory into KSS for LCBPs. In the end, a holistic framework that synthesized strategic and theoretical dimensions was presented in order to analyse two types of current KSSs of the two case studies.

3 Research Approach

§ 3.1 Introduction

This chapter explains the research approach used to investigate current Knowledge Sharing Strategies (KSS) for Large Complex Building Projects (LCBPs). This study has been designed as a qualitative study using a comparative analysis of two cases. The research was conducted in the Design and Construction (D&C) industry with two case studies having been selected to serve as examples of real-life LCBPs. Firstly, the rationale of the research design is described for analysing the knowledge sharing processes of the actors involved in LCBPs. Secondly, the selected cases are described by first giving an overviews and then a detailed account of the two LCBPs. The overviews provide a general timeline of the project processes, whereas the detailed descriptions focus on the two different approaches explored in each of the two cases. Thirdly, an overview of the collected data and the coding scheme developed to analyse the two cases is given. This chapter concludes with the method of confirmation of the generalizability of the research results.

§ 3.2 Research Approach

The research approach has been designed to investigate the nature of large complex building projects and to understand the challenges for knowledge sharing and the shortcomings of current approaches. Large complex building projects are socially and culturally complex settings. Attempting to theorize knowledge sharing in such as setting requires rich data that allows for theory building about the behaviour of design team actors. This requires studying the phenomenon in question in its natural setting – any abstraction or simplification of the setting would render it impossible to capture and understand the challenges that actors in LCPBs are exposed to. Therefore, a qualitative research methodology was adopted to address this complex social and cultural phenomenon (Klein et al. 1999) that involves human discourse (Miles et al. 1999). Furthermore, very few empirical studies have been conducted on the actual practices of knowledge sharing in LCBPs, particularly not at the inter-organisational level (Creswell 2009). This made an explorative study with a qualitative analysis a suitable approach.

Finally, the theoretical framework of this study draws on Activity Theory, which views knowledge sharing as a social practice and lends itself to in-depth field research with rich detail. Therefore, a comparative analysis of two cases has been intended.

The case studies provide empirical descriptions of specific instances describing phenomena that are typically based on a variety of data sources (Eisenhardt 1989; Yin 1994; Eisenhardt et al. 2007), that provide rich descriptions (Kidder, 1982) and that can be used to test a theory (Gersik, 1988; Harris & Sutton, 1986; (Eisenhardt 1989). Regarding the number of the cases to be investigated, a single case study gives an in-depth understanding of one particular case by covering the objectives of a given organization which take part in a particular project (Yin 1994). Single case studies can provide the basis for theory building, but these are also limited by the particular setting that is being studied. A comparative analysis, however, allows researchers to perform focused comparisons so that they can reach conclusions concerning the necessary and sufficient conditions giving rise to a certain phenomenon of interest (George et al. 2005). This comparative analsis based on in-depth case studies enables researchers to understand a complex issue or object (Eisenhardt 1989), to extend experience or to reinforce what is already known (Yin 2002).

In the context of KSS for LCBPs, a comparative analysis of two cases provides an opportunity for investigating different project settings by using the same dynamics of knowledge sharing processes (i.e. social interactions, exchange of design objects, tool types, and uses) and strategies individually. Compared to a single case, a comparative analysis based on two cases provides a better basis for generalization to portray the extent of LCBPs and current KSSs. Therefore, by comparing the differences and similarities in a different setting, a broader understanding of the knowledge sharing processes of actors can be gained. Moreover, a better view of current KSS in real-life LCBPs can then be obtained.

Two real-life LCBPs were selected that resemble the two types of approaches to knowledge sharing discussed in § 2.4.7. Case 1 is a renovation of an underground railway station and it represents a people-oriented approach to knowledge sharing. Case 2 is a railway station project and it represents a tool-oriented approach.

Two concerns arise when selecting and defining the number of cases; generalization problems and the availability of projects suitable for the analysis. The first concern is the number of cases. One can argue that two cases may not render a complete understanding, and therefore more cases are needed to cover the different varieties of current KSS. The concern would be that more than two cases are needed for better generalization. In this study, the focus is on gaining an understanding of the knowledge sharing mechanisms and not on testing a theory, for example, how knowledge is shared. Choosing two cases allowed for sufficient depth in analysing each case individually, and for comparing the people and tool-oriented approaches against each other. Selecting two cases therefore was chosen in order to conduct these analyses using a manageable amount of data. Moreover, the questions that needed to be answered in this study required in-depth investigations of cases, such as understanding the actual behaviours of actors involved in the design process or the reasons for actors sharing or not sharing their knowledge. This investigation brings the necessity of data collection via the observation of actors involved in the design process. Therefore, data collection required being in a close relationship with the actors in order to monitor their knowledge sharing processes. For monitoring and accurately investigating the knowledge sharing processes of actors, the density of the observation moments becomes important. In Case 1, observations were conducted in a co-location office, involving social interactions (face-to-face and distant) and the use of physical settings (informal and formal interaction environments), the tool-uses of actors. Here, the rules and procedures that the design teams applied and the reactions of the actors towards rules became essential. In Case 2, understanding and observing the actors who initiated the BIM tool involved observing the way the actors used BIM, the social and distant interactions around BIM and these interactions supported by tools. Thus, the two case studies have been designed to accommodate an intensive observation of actors, their work environments, including their design processes over the course of time. In addition, identifying the causal mechanisms of knowledge sharing of actors in LCBPs requires the deep, contextual knowledge gained from these two intensive case studies.

The second concern is the availability of projects that are suitable for conducting this type of analysis. As identified in § 1.1, LCBPs require a great number of resources and a long process of land provision and selection of project actors. They are also characterized by a long process of requirement definition negotiated between a large number of parties (governments, private sector investors, local authorities, designers, project managers, etc.) and a long duration until actual completion. In the European context, airports, transportation buildings, multi-use stadiums can all be viewed as LCBPs. Finding a project that a) fits the criteria set in § 1.1 and b) is at a stage where the design process has been narrowed down and the selection of the cases can be investigated thoroughly, limits the choice of suitable cases to study. Given these criteria, there appeared to be only few suitable projects at the time of this study to which the supervisory team and I could negotiate access. Taking this into consideration, we subsequently selected a redevelopment of an underground station project and a new train station project within two different EU countries.

§ 3.3 Data Collection

The data collection of the two case studies was targeted towards the themes related to knowledge sharing in LCBPs. The themes were defined by relating the aspects of knowledge sharing of actors and the strategies adopted for fostering knowledge sharing in LCBPs. The data was collected on current social and distant interactions of actors involved in design processes of the two cases, the tools, and rules of interactions that all led to the ways that actors share their knowledge. It was collected through two intensive periods of fieldwork. For both cases, the fieldwork comprised a full-time observation period conducted in the physical space of the design teams.

The duration of the fieldwork for the two case studies varied. For Case 1, I began in March 2008 and it lasted four months. It consisted of three-week full-time observation period within the co-located design office and of a further period where the missing data was collected through telephone and Skype meetings. During the fieldwork, I kept an observation diary. In addition to the observation diary, I collected data comprised interviews, e-mails between actors, project documents gathered from the repositories of organizations (such as client representatives and engineering firm), minutes of meetings, presentations prepared by client and design teams to communicate with stakeholders or public. I collected the missing data through using the telephone and during Skype conversations with the assistant manager of the program management discipline and the assistant project manager of the structural engineering crew. These observations and interactions took place in the period April - July 2008.

The second case study started on 2 December 2009 and lasted until June 2010. It comprised six months of full-time observation conducted in the engineering firm that was responsible for multiple project disciplines. I collected the empirical data including interviews, video recordings, project documentaries, pictures, emails, and meeting minutes. The data also included retrospective accounts of the projects as well as a real-time update of the project progresses.

In both cases, the data collection was done through interviews, observation diaries, video recordings of the meetings (held in mono and multi-disciplinary levels), both minutes and memos of the meetings (in managerial, technical and stakeholders levels), e-mails (sent and stored between actors) and their attachments, workshop reports, design precedents, and phase documents (design deliverables submitted to the client). I conducted in total 34 interviews. Case 1 comprised nineteen interviewees from twelve disciplines (program managers, project managers, commercial managers, building physics, architects, overall design manager, fire prevention consultant, tunnelling, electrical engineering, public health, IT/knowledge manager, client representatives) in six organizations. Case 2 comprised fifteen interviewees from seven disciplines (structural engineering project leaders, site conditioning, HVAC, project managers, architects, and the client representative) in five organizations. All interviews were semi-structured and lasted approximately one hour each. They were tape-recorded and transcribed (see Table 3).

In this study, I regarded the interviews as an essential, yet insufficient basis for understanding knowledge sharing practices. The interviews represent the perspectives of the project actors, which is necessary to understand their perceptions of the social interactions, the tools used for design representation and easing knowledge sharing among people, and the way they see 'others' (i.e. the members of different disciplines and/or organizations) as collaborators or contradictors in the design process. The subjectivity of the interviewees is pre-accepted and taken into account with this awareness. Eisenhardt et al. (2007) and Dainty et al. (1997) particularly address the challenge of interviews for the qualitative researchers, as interviewees likely to provide contradictory data. To put it simply, I treat the 'texts' of people as representing subjective stories under the influence of personal, disciplinary and organizational project history. In order to deal with this subjectivity, I focused on the full-time non-participant observation of people in their work environments.

The most suitable approach involved remaining distant and not becoming directly involved in regard to the field of analysis (large complex building projects) and the components of knowledge sharing strategies (individual and organizational actors, artefacts, tools, rules, and division of work. I systematically kept a diary containing behaviours of actors, disciplinary/ multi-disciplinary interactions, artefacts production, formal and informal internal/external sharing methods. Furthermore, I collected project schemes and organizational charts, which were continuously updated and checked against interview statements. Videotaping the interactions and audiotaping the interviews was also done in addition to gathering project documents (artefacts, official design precedents, regulations etc.), the interviewees were selected from designers, managers, and client representatives. The interviewees represented their perspective, gave their self-perception on design processes, interactions within design teams, and design practices of the participant organizations. I complemented the data gathered through the interviews with audio/visual data such as pictures, video recordings, etc. In this intensive fieldwork, a danger lies in the objectivity of the researcher who may not remain detached from the data. I attempted to avoid subjectivity through the periodic discussions of the analysis of the data with the supervisory team.

§ 3.4 Data Analysis

This study required an analysis of the knowledge sharing behaviours of actors, and the actors' knowledge sharing mechanisms used in the design process. Based on our theoretical framework developed in chapter 2, I aimed to identify the challenges for knowledge sharing in LCBPs, the deliberate and emergent strategies used to address these, and the social practices, tools and procedures associated with these strategies. I therefore analysed how actors interacted in their design environment, how they engaged face-to-face and across distances, how they exchanged and processed information and how they used tool for designing and knowledge sharing. I developed a coding scheme on the themes of knowledge sharing differentiating actors, their practices, their knowledge sharing processes across organizational, hierarchical, and disciplinary boundaries, and the impact of the physical and tool-supported environments. In the end, eight codes have been defined to analyse the two cases. The list of codes is given in Table 2.

Code Name	Definition of Code
Project Challenges	This code represents the current challenges of LCBPs, which have high risk to hinder the current process of design currently discouraging the design team and the client organizations in taking deliberate actions to design and implement KSSs. This code comprises six aspects; chains of procedures, change of criteria, change of staff, cost reduction, size, and uniqueness.
Design Changes	This code identifies the design changes as natural evolvements between problem and solution spaces in the design process. It is to distinguish regular design changes from re-design activities, which are due to the change of design criteria in LCBPs. This code is used to classify the current practices activities regarding design problem and corresponding solutions. This is highly linked with the organizational practices.
Organizational Practices	This code identifies the differences between organizational practices in a design process of LCBPs. It is to understand the activities of the actors carried out disciplinarily, organizationally and/or individually in order to achieve the project objectives (disciplinary/organizational) in design process of the projects. This code makes visible the potential influences of the different organizational practices towards the way that shared practices formed in the design environment. It enables us to distinguish how actors who contribute the design process with their organizational practices enact the mechanisms of knowledge sharing differently/similarly in LCBPs.
Boundaries	This code defines boundaries of the actors in a project environment, as they exist between 1) organizations 2) design crews in multi-disciplinary organizations (i.e. full service companies). Functional specialism, discipline types, or contractual relationships draw them and add legal, physical, and social character to the boundaries. This code becomes important to see the way that in which events/moments and by whose initiative the actors loosen or thicken their boundaries and engage in less knowledge sharing activities in a design environment.

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Code Name	Definition of Code
Actors	This code is profiles which actor involves in what type of mechanisms of knowledge sharing in the design process. It is to distinguish the way that deliberate knowledge sharing strategies are enacted and expose differentiating organizational design practices through pointing out where actors blame and praise each other; try to have empathy (perspective taking), how they position themselves and perceive each other, and where and how the actors take initiative towards knowledge sharing in LCBPs.
Deliberate Knowledge Sharing Strategies	This code brings both intended and emergent knowledge sharing strategies implemented in LCBPs to the surface. It is to demonstrate who design and initiate the KSS, what type of operations intended and implemented with regard to KSS through incorporating with the way that actors enact these operations.
Environment	This code is describes the settings planned in the project environment of LCBPs. The environment comprises both physical (where actors engage in face-to-face conversations) and virtual settings (where actors perform their activities in a tool-mediated environment) with both informal and formal purposes. This code is to understand both the properties and the challenges of multi-disciplinary environments in which actors either are virtually or physically present with their knowledge.
Knowledge Sharing	This code deals with both active and passive ways of knowledge sharing processes. It is to understand the current knowledge sharing processes of actors through identifying where actors interact and participate to design dialogues actively; interpret the boundary objects (i.e. design representations), and observe others' way of doing things (i.e. sketching, problem solving, building design argumentation, interpretation of boundary objects etc.). This code is to build understanding of the way that actors engage in knowledge sharing processes in LCBPs. This code is also to understand the problems encountering in knowledge sharing with regard to these activities of actors.
Tools	This code identifies the IT based mechanisms which provide infrastructure to KSS (i.e. BIM, CAD systems, information repositories, product and process modelling efforts, intranets and other software packages developed for particular design and construction problems, communication tools). It is to investigate that tools are used to facilitate actors in knowledge sharing process.
Description of the Project	This code is to provide understanding on the project characteristics in LCBPs such as the organizational structure of the design and client teams, the size and scale of the projects, the budget, profiles of the organizations, the time duration, the way that projects are initiated and legally bond etc.

Table 2
List of codes and explanations

I coded the data by using a qualitative research software program. Triangulation of the data sources was used to interpret the findings. When there were contradictory data, a special attention is paid to trace to find out the most accurate information. This included iteration in terms of data collection. When there was a factual contradiction (i.e. the inconsistent numbers, dates etc.), I tried to investigate the 'truth' by conducting a second round of questions focusing on particular inconsistency. In parallel to this process, I looked at the other data sources such as public information, online project reports in order to have the accurate information. When there was a contradiction about issues, such as perception of other actors, I paid special attention to figure out whether the contradiction is through differing personal experiences or group behaviour of the disciplines.

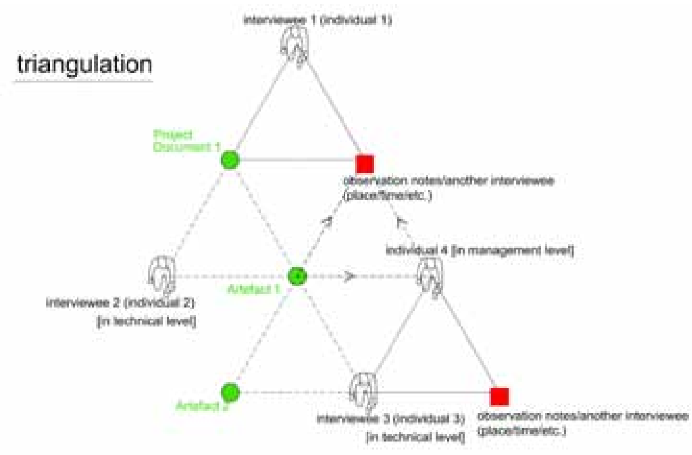

Figure 17
Triangulation of the collected and coded data in this study (© Bektaş)

The triangulation process based on different data sources is illustrated in Figure 17. Meetings and a feedback session with the supervisory team were held for confirming the analysis and findings.

The codes provided a lens to look at the dynamics that influence the knowledge sharing processes of actors within the LCPBs design teams. Each main research question required a different set of codes. For the first research question, the codes were used to understand the nature of LCBPs, their challenges (cost reductions, chains of procedures, changes in personnel and design criteria, the impact of design changes as the project progresses, current organizational practices, as well as project descriptions. Therefore, codes 1, 2, 3, and 10 were emphasized the most.

Focus of the First Research Question: Characteristics of LCBPs

Code 1: Project Challenges (Chains of Procedures, Change of Criteria, Change of Staff, Cost Reduction, Size, and Uniqueness), **Code 2: Design Changes** (Including Problems with Design Changes) and **Code 10: Description of the Project**

Focus of the Second Research Question: Knowledge Sharing Strategies in LCBPS

Code 6: DKSS (BIM, Collocation, Regular Meetings, Workshops)
Knowledge Sharing

Tool Aspects	**Social Aspects**	**Procedural Aspects**
Code 2: Design Changes (Including Problems with Design Changes) **Code 9: Tools** (Enabling Tools, Problems with Tools)	**Code 4: Boundaries** (Disciplinary, Hierarchical, Organizational, Overcoming Boundaries) **Code 5: Actors** (Blaming Others, Perception of Others, Perspective Taking, Praising Others, Taking Initiative) **Code 7: Environment** (Face-to-face, Informal, Challenges) **Code 8: Knowledge Sharing** (Active Participation, Interpretation of Design Representations, Passive Observation, Problems)	**Code 3: Organizational Practices** (Collaboration, Lack of Collaboration) **Code 1:** Chains of Procedures

Figure 18
Codes in relation to the two empirical research questions

For the second research question the main codes included the strategies implemented, the actors, their boundaries (disciplinary, hierarchical, organizational), the tools that supported crossing the boundaries and interaction for active and passive participation in knowledge sharing, the environments (physically co-located and distributed) as well as the codes used for the first research question. In other words, all codes were used to answer the second question. The codes and the relationship with the themes of this study are illustrated inFigure 18.

In order to analyse the collected data, the software program Atlas.ti was used. The collected data was tagged with an appropriate code or codes, and categorized under a research theme. The analysis was done by synthesizing the tagged and categorized data sources. In this synthesis, the triangulation method was used as illustrated in Figure 17. And the research steps can be seen in Figure 19.

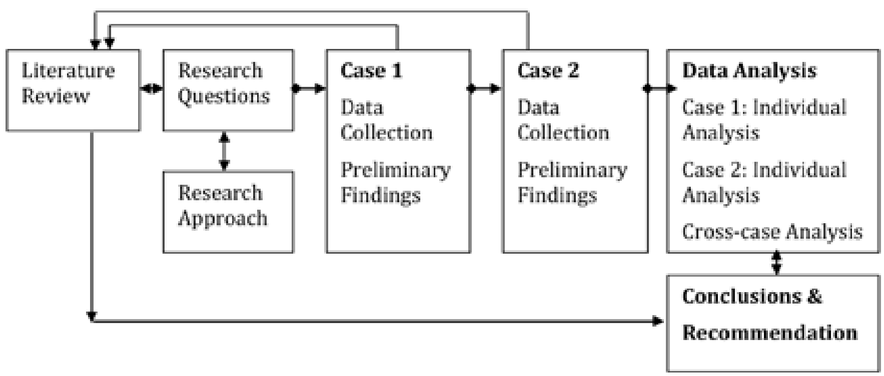

Figure 19
the Research Steps

The Figure 19 illustrates the steps taken for this research and connection between these steps. The steps are illustrated as 'boxes' and the texts within the boxes define the main outcome of each step. The arrows represent how the steps are in relation with others such as linear or iterative. The research started with an extensive literature review. The review was necessary to define the research questions and find suitable approach to answer these questions. At this early stage, literature review enabled us to see that there is lack of attention for inter-organizational knowledge sharing processes. The first research questions therefore were formulated as asking whether there are strategies dealing with knowledge sharing in inter-organizational level.

The iterative process among literature review and formulating research questions and the research approach lead us to concentrate on large complex building projects and selection of incidents of such projects in order to investigate the current inter-organizational knowledge sharing strategies. In other words, the initial questions targeted at the necessity of both inter-organizational knowledge sharing in LCBPs and deliberate strategies dealing with knowledge sharing. However, existing strategies needed to be explored. Therefore, examining LCBPs and their KSSs became important. At first, the first case (case 1) is selected as an example of a LCBPs based on the criteria defined in § 1.1. Case 1 represented a strategy (called co-location) that focused on people and social interactions through providing a long-term physical setting for the disciplines. Through the data collection and the preliminary insights gained by the initial findings, the research questions and research approach were sharpened. While gathering preliminary insights from case 1, the exact research gap is found; there are approaches dealing with inter-organizational knowledge sharing but there is a lack of strategic framework for practitioners to develop project-specific knowledge sharing strategies. This meant that a framework for knowledge sharing strategies needed to be built. By using the framework developed, the second case study (case 2) is selected and conducted. The similar iterative process between research questions and case study data collection (through preliminary insights) is followed. Through the preliminary findings and insights gained in case 2, the framework for knowledge sharing strategies is revised and the Knowledge Diamond framework is derived. The Knowledge Diamond framework was produced to analyze the content of the selected approaches in two cases. And through the literature review, the strategic concepts are embedded to the Knowledge Diamond framework and a holistic framework for knowledge sharing strategies is generated. Through this holistic framework, the final data analysis started. Firstly, the individual case analyses were done as co-location as an example of people-oriented KSS, 'BIM' (3D Model) as a tool-oriented KSS were analysed. Following to the individual analyses, the cross-case analysis was conducted in order to identify commonalities and differences. Based on the analysis, and by checking the literature reviewed in early steps, the conclusions were drawn. Moreover, practical recommendations are provided.

One can notice the different kind of arrows as connecting 1) research questions to Case 1 data collection; 2) Case 1 to Case 2 data collection; 3) Case 2 data collection to the ultimate data analysis. Those three illustrated 'colloquia' –evaluation moments conducted with two referees (consisted of experts/academics experienced in this field of study) with a public presentation.

	Case 1: Renovation of an Underground Station	Case 2: New Train Station Complex
Observations	3 weeks full-time non-participant observation (120 hours)	6 months full-time non-participant observation (880 hours)
Documents	162 documents (30 minutes of meetings and their agendas, 4 emails between actors,	687 documents (167 minutes of mee-tings and their agendas, 149 emails between actors,
	28 fact sheets as project schedule,	19 fact sheets as project schedule,
	13 power point presentations used for project deliverables,	5 power point presentations used for project deliverables,
	38 pictures,	322 pictures,
	3 organograms,	1 organogram,
	3 official layouts of co-locations,	2 official layouts of the Engineering Firm 2,
	3 communication and link charts,	1 overall policy of the Engineering Firm 2, 1 rule for tool use,
	7 organizational guidelines and project procedures,	15 hours of video recordings of the meetings, design workshops,
	9 reports including a seminar report on major projects and a project report both includes this case,	6 information booklets and reports about the project and design organi-zations,
	2 information booklets about the project,	3 outputs of the company intranet)
	13 outputs of the knowledge manage-ment system)	
Interviews	18 open-ended audio-recorded inter-views (approx. 27 hours in total)	15 open-ended audio-recorded inter-views (approx. 30 hours)
Number of Disciplines	13 disciplines (program/design/ IT-Knowledge management, building physics, accounting, architecture, fire consultancy, tunnelling, electrical engi-neering, public health, project sponsors)	6 Disciplines (structural engineering, mechanical engineering HVAC, archi-tecture, project management, overall design management, conditioning, and project sponsor as client)
Number of Disciplines	6 months of data collection	18 months of data collection

Table 3
Overview of data collected in the two cases

§ 3.5 Confirmation of Results: The Expert Panel

In order to confirm the generalizability of the findings from this research and to check whether they may be generalised beyond these two cases, an expert panel was organized to present and discuss the results. The aim was to test whether the research results obtained were also experienced in other large complex building projects. For this panel, eight senior-level practitioners who had experience in different LCBPs were invited. Each expert represented a different knowledge domain and their perspectives varied in regard to the different projects. The aim of the workshop was to combine the different perspectives that take place during each large complex building project and to gather the feedback received from the different knowledge domains in our findings. The panel provided an inter-disciplinary perspective in which each representative reviewed the research findings from their organizational and disciplinary perspective. This validation method enabled us to compare our findings against experiences of the participants in other examples of LCBPs. This was essential for the potential generalisation of the research findings. The content of the panel comprised three sessions. In the first session, the first main research question and the empirical findings were drawn and discussed. In the second session, the second research question and the related empirical findings were discussed. In the third session, the practical implications of the potential KSS for future LCBPs were provided. Details of the process of the expert panel and insights resulting from it can be found in chapter 6 as part of the discussion.

§ 3.6 Case Descriptions

This section covers the case descriptions of the two LCBPs. Firstly, an overview is given for both cases, which is then followed by detailed descriptions per case. In these overviews, a general timeline for the client team and the design team interactions, as well as the development of scope are given chronologically. These overviews are particularly targeted at analysing the nature of LCBPs and they provide a general picture of the two projects, which are later analysed in Chapter 4.

Secondly, the detailed descriptions of both cases are given. The detailed case descriptions focus on the selected approaches that deal with knowledge sharing problems in each case. Case 1 represents a people-oriented approach using co-location. Case 2 represents a tool-oriented approach using BIM. Based on these detailed descriptions, the current knowledge sharing strategies of these two projects are analysed. This analysis is further detailed in Chapter 5.

§ 3.6.1 Overview of Case 1

Case 1 was an £800 million architectural restoration and extension project. It involved one of the most frequently used railway and metro stations in a major European city. The client comprised three organizations: the Ministry of Transportation (referred to as the 'shadow client'), the Underground Body (a public organization responsible for metropolitan-wide underground works and referred to as 'the front line client'), and a private consortium (the private client appointed during the course of the project as a result of privatization).

The Ministry of Transportation gave the preliminary project approval to their transportation department in 1996 in order to initiate the project. The department then selected the underground body as a client to work out the project. The department and the underground body negotiated for three years in order to clarify the project scope, to distribute responsibilities, and to negotiate the role of the two public bodies as clients of the project. In the end, the project contained two phases involving the refurbishment of the existing ticket hall and the design and construction of a new ticket hall. The time line of the project is illustrated in Figure 20.

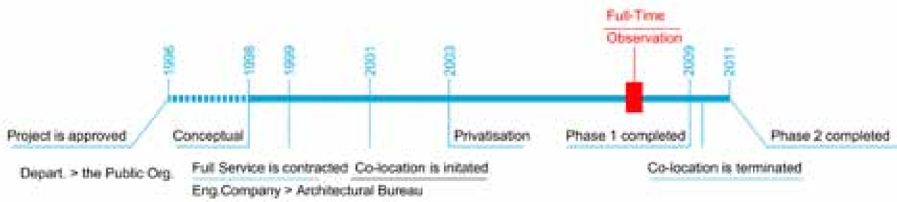

Figure 20
Case 1 timeline (© Bektaş)

In 1999, the underground body hired a globally-known engineering company for the overall project design work. This included the following disciplines: architecture, HVAC, structural design, survey, construction planning, traffic, health & safety, quantity surveying, planning and consents, environmental, value engineering, and acoustics. The selection of the engineering company was based on a conceptual design produced on request of the underground body by a 'one-man' architectural company. As a leading designer, the engineering company was then able to select an architectural firm with a significant degree of experience in complex underground projects. Even though the firm had an in-house architectural department, the firm subcontracted an architectural firm with a nation-wide reputation.

When the engineering company became involved, they re-designed the conceptual design, although the basic concept design did not fulfil the more recent requirements for the year 1999. On the one hand, the station was located in a historical setting. This meant that many regulations had to be taken into account and a number of authorities were involved in the design. This required a delicate approach regarding the historical neighbourhood and structural aspects. Furthermore, a new fire regulation was implemented just before the project started. Thus, the design of the project needed to comply with these regulations and therefore the initial concept design on which the tender had been based was outdated. The client used this updated regulation as an opportunity to increase the number of passengers, thus renewing the program requirements. This update resulted in a project re-design. In order to deal with the complex design task and potential re-design work, the engineering firm co-located the design team organizations. This co-location physically brought all main disciplines together into one shared open-plan office. The main disciplines at the co-location included architecture, public health, tunnelling, program management, project management, and finance.

In 2001, while the design team organizations worked on the design in co-location, the Ministry of Transportation asked the department to integrate the project into the surrounding transportation projects. The surrounding projects included railway projects and their new ticket halls. These projects had different clients and design team organizations. The integration of different project scopes required the synchronization of different design teams and project clients. This synchronization works resulted in a suspension of Phase 2.

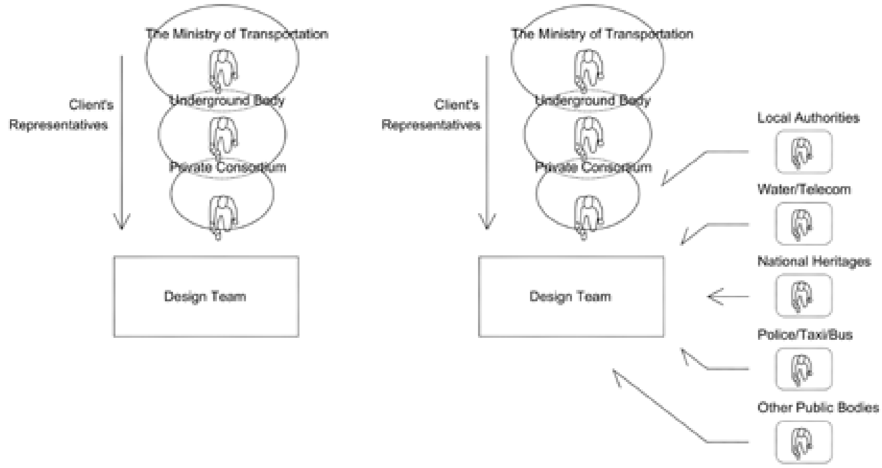

Figure 21

Figure 21a (left) Client organizations

Figure 21b (right) The influence of stakeholders in design process in Case 1 (© Bektaş)

In 2003, while the design work continued including Phase 2, the government achieved the implementation of its privatisation policy and appointed a privately owned consortium for developing railway projects under a PPP contract (Public-Private Partnership). This contractual change resulted in organizational and structural alterations of the client's design team and design task (see Figure 21). As a consequence, the private consortium became the new client and it severed the direct relationship between the two public bodies (the department and the underground bodies) and the design team organizations. This change of client (from public to private) affected the chain of command. This organizational change resulted in a new client team that consisted of new people, new organizational objectives, and different methodologies to achieve these objectives and it included changes in the project scope. This change resulted again in the re-designing of the project in order to respond to the changed criteria driven by the 'new' client. With this new structure, the design and construction of the project was only completed in 2010.

§ 3.6.2 Overview of Case 2

The second case (Case 2) was a €150 million-euro railway project, which was to become one of the five stations in the country to connect two major European cities. The scope contained a new terminal complex consisting of platforms, a bus station, passenger tunnels, office buildings and apartments, and an elevated car park on the roof of the station building. Due to the mixed-use of the station, a variety of project sponsors with different interests was involved.

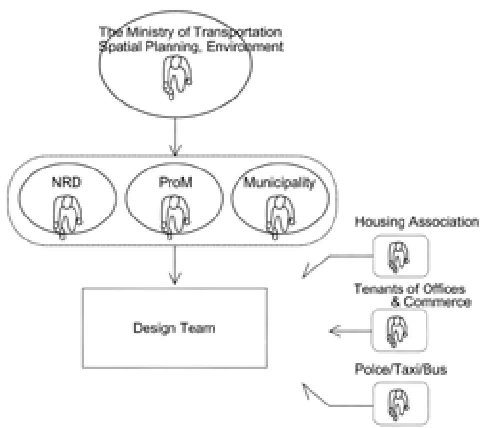

Figure 22
Client organizations and stakeholders and their influence in the design process in Case 2 (© Bektaş)

The client was a consortium including a National Railway Developer (NRD), the City Municipality, the Province, the Ministry of Transportation, and the Ministry of Housing and Environment (see Figure 22). This consortium appointed a public company as overall project manager (ProM). ProM was interested in the station and its connectivity to the other large hubs. The municipality's interest was related to the spatial development in which the railway station was to become one of the main landmarks, and which would increase the use of urban space and liven up to city centre. The NRD was interested in exploiting the areas to be built around the station.

The architectural design was chosen by holding an architectural design competition. A design proposal submitted by an architectural office with a national reputation and a landscape design agency was selected. The client's motivation for selecting this proposal was due to the architects' vision, which was seen as being "*progressive, non-conventional and ambitious with a unique character*" (Official website of ProM, 2008).

The project was described by the client representative as "… [U]*nlike many railway station projects, this project comprised various functions in one building; it will be "the building of the city*"…." (Client Representative, 2004). The client selected the design because it proposed a 'building of the city'. The firm of architects literally assigned all the functions to one single building together with an urban design agency. This mono-building concept comprised the tunnelling, commercial spaces (including service areas), railway tracks, two entrances, parking garage, housing, and office blocks. The design proposal connected the current two districts previously divided by the existing station - forming 'the front and the rear of the station' (see Figure 23).

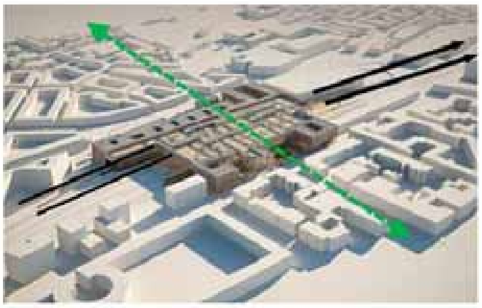

Figure 23

Figure 23a (left) Future station and the existing city districts to be connected through the new station building (the area in magenta represents the location of the station).

Figure 23b (right) Design proposal representing 'the building of the city' with various functions in additions to public transportation hub..

This new 'one building' contained 'city functions' and included residential blocks, offices, commercial spaces and a parking garage. The scope was to construct a highly efficient transport terminal that would improve the connection between two major regions. The program comprised integrating shops, amenities, a conference/business centre, a prestigious residential location and a key pedestrian and cycle route connection from the city centre to the northern districts. The aim was to construct a terminal that would have no front or rear entrance; both sides would be of equal importance and would be given their own visual identity.

The client appointed an engineering firm experienced in large infrastructure projects. The firm was responsible for the conceptual design based on the architectural design.

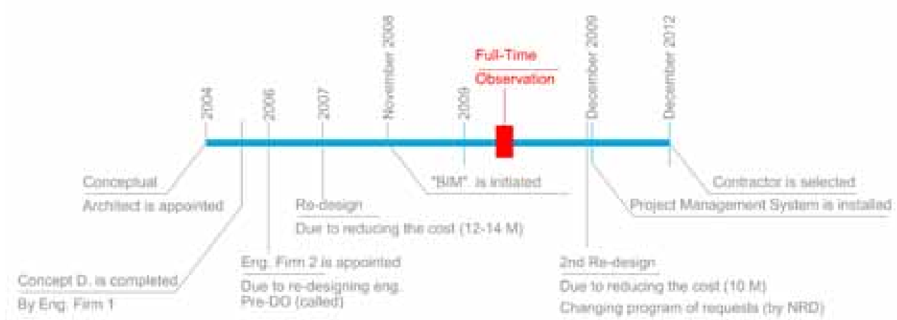

Figure 24
Timeline of Case 2 (© Bektaş)

In 2005, Engineering Firm 1, together with the two other firms, set up an engineering consortium. The second engineering firm had a significant level of experience in building design and the third firm was a sector-leader in the signalization work of transportation projects. As a result of this new organizational bond, the division of work was based on each company's areas of expertise such as 1) building engineering service, 2) conditioning and tunnelling, and 3) signalling works in the station. This resulted in an organizational shift in the design team, which included two additional parties (see Figure 25). This institutional change occurred between two phases (preliminary design to definite design), and resulted in a new role distribution based on the knowledge domains of the forms. With their new roles, Engineering Firm 2 re-designed the existing structural design, which had initially been done by the Engineering Firm. 1. This meant that there was a new design process based on the previous submission, and a new reference design of engineering services prepared by the new building engineering firm involved. In order to avoid any confusion and conflict, the new reference design was called 'pre-DD' meaning preliminary definitive design in January 2007. While the design team was busy elaborating the design, due to changing market conditions, the client required a cost-reduction (€10 m) from the design team in 2007. The client changed the criteria in order to increase the profitability of the project. This was reflected in the downsizing of the current design. The definitive design (i.e. final design) was completed in July 2007 including the client's cost-reduction.

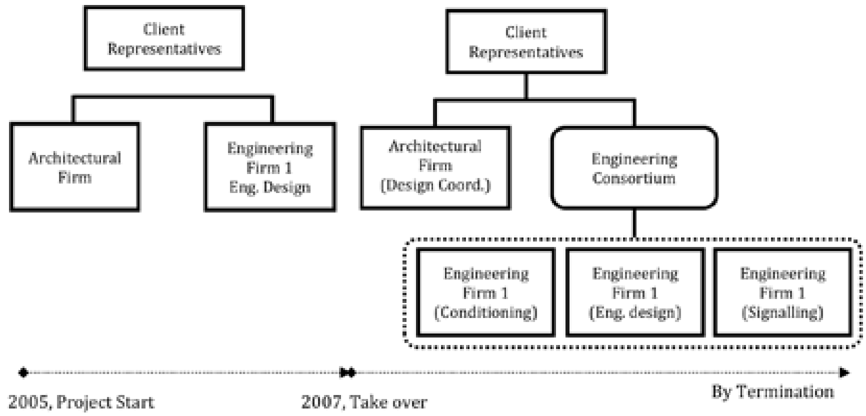

Figure 25
Change in the organizational structure during the preliminary design 2005 - 2006 (© Bektaş)

In 2009, the project had more significant redesign work, due to another cost reduction (€10 m) imposed by the client. These cuts were due to the changed requirements of the client over time and the involvement of prospective officeholders throughout the design process. NRD changed their criteria in order to increase profitability. In 2008, the design was updated based on the new criteria. However, due to major design changes, integration and controlling the design information from various disciplines became difficult. Synchronization problems occurred in the design team. Therefore, in November 2008, a 3D model was developed by a draftsman of the structural design crew in order to tackle the design changes. The aim was to share a single interactive tool between all the designers. The draftsman's first intention was to integrate all the design disciplines into one model so that the design changes could be incorporated in the downscaling process.

In mid-2009, the client imposed another cost reduction due to changing market conditions, which was aimed at reducing the overall costs by € 10m. The changing market resulted in 're-redesign' proposals. At the beginning of January 2010, two different design teams started to work in parallel on two different design versions. The first version was the initial design process without the €10m cut and the second version was called 'second track' and included the options to reduce the initial design budget by €10m . In June 2011, the client stopped the second track. By the end of 2011, the contractor had been selected. The project was expected to complete in 2012 (see Figure 24).

§ 3.6.3 Case 1:Co-location as a People-oriented Approach

Co-location refers to a shared office space used by the design team actors who worked throughout the design process. The engineering firm responsible for the overall design work decided to move their staff to a co-located office space in 1999. It was a top-down strategy intended to create a physically shared, inter-organizational open office, where people from the main design disciplines could be accommodated. The co-location was situated in an office in the city centre of a major European city. It consisted of approximately 400-m2 of office space, which accommodated eleven departments comprising architecture, structural, mechanical engineering, electrical engineering, public health, commercial, document management, tunnelling, program management, site liaison, and the CAD group. In the 400 m2-office space, each discipline had its own working island (see Figure 26). It provided office space for two companies, the engineering firm, and the firm of architects, and had client representatives from the private consortium working there intermittently up until 2010.

The main intention behind co-location was to bring the main design disciplines together in one physical environment in order to synchronize the design processes of these disciplines. The main enterprises included activities like managing numerous interfaces among the various disciplines, dealing with dynamic issues of the project such as the difficulty of managing design elaboration, smoothing the information flow (Lead HVAC engineer, 2008), and making major scale changes. Co-location was an implementation embracing the different design crews representing three different organizations: the firm of architects, the global engineering firm, and the private consortium.

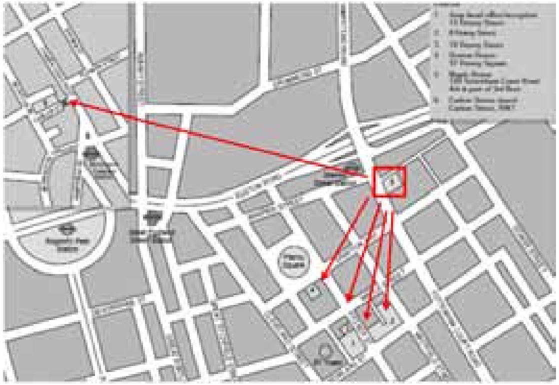

Figure 26
Official map of the Engineering firm's offices in relation to the co-located design team's office

The initiators of the co-location aimed to provide a long-term and physically shared setting that could accommodate and create a shared-design practice formed by the participating organizations. It accommodated the design activities that were performed by the design team members, and lasted for the duration of the project. The participant organizations were brought to the same setting by being detached from their parent organizations. By creating a shared-physical setting, an attempt was made to reduce the barriers by increasing the frequency of informal and ad hoc interactions across the different disciplines.

The location of the co-located offices was chosen so that it would be close to the headquarters of the engineering company that had several offices in the neighbourhood. Co-location was organized as an extension of the current offices of the engineering firm so that the participants could easily communicate with the non-collocated disciplines. Co-location was meant to bring proximity to the design team organizations. Yet, it was also organized so that it could bring this proximity to the other offices of the engineering firms as shown in Figure 27. The strategy initiators regarded the proximity of the actors to one another and to the main organization as an important aspect:

"... [W]*e have offices in this area so therefore it was felt that providing main disciplines; so architecture, structural, urban services, etc. providing them co-located, we can then call anybody else when needed. Again that worked very well...*" (Program Manager of the Engineering Company, 2008)

The remark above made by the program manager exemplifies the importance of the physical proximity. The relationship between co-location and the other offices of the engineering firm is illustrated in Figure 26.

The co-location strategy emphasized physical settings that attempted to enhance face-to-face interaction in both a formal and an informal manner and which accommodated tools for the actors. The following section describes how this impacted on the actors involved and the tools used in co-location.

§ 3.6.3.1 People in Co-located Offices

The co-located offices accommodated between 89 and 151 people at any given time. The physical setting was divided into eleven disciplinary islands allocated to the design crews, which included both work and interaction spaces. In these workspaces, designers performed their disciplinary design activities. They produced artefacts synchronously, since co-location potentially offers the opportunity for shared-design activity in a long-term and shared physical setting.

The interaction spaces accommodated both formal and/or informal interactions. These spaces potentially accommodated inter-organizational and/or inter-disciplinary conversations such as ad hoc or planned design dialogues, sketches, or artefacts that needed to be discussed. The workspaces were organized based on the division of work in the co-location, as each discipline had their own private disciplinary islands. Only one discipline displayed a distinct character in terms of the allocated working space: commercial management. The commercial crew included five members who worked together in a separate room adjacent to the meeting room (shown in the upper-left-hand corner in the Figure 28a). This was due to the confidentiality required for commercial issues. The interaction spaces comprised formal rooms (i.e. for meetings and workshops) and informal areas where 'discussion tables' determined the interaction space. There were two formal interaction areas and six informal interaction spaces for eleven disciplines as illustrated in Figure 27. Figure 27 shows the official layout of co-location containing the knowledge domains (colour-coded) and their division in the physical setting. In the layout, 89 individuals worked in co-location.

As illustrated in Figure 27, the crew size varied from four to sixteen individuals. The smallest crew was the document control crew, whereas the largest was architecture, with 16 designers. In the 2006 version, there were 14 structural engineers. In the layout of the co-located office, the architecture crew was initially supposed to be located in the middle of the office space, within close distance of structure, electrical, program manager, and tunnelling. Based on the layout of the co-located design team dated 24 May 2008, the position of the architectural crew was shifted to the area used by the structural engineering crew as the number of structural engineers had been increased to 20 and the number of architects downsized to nine.

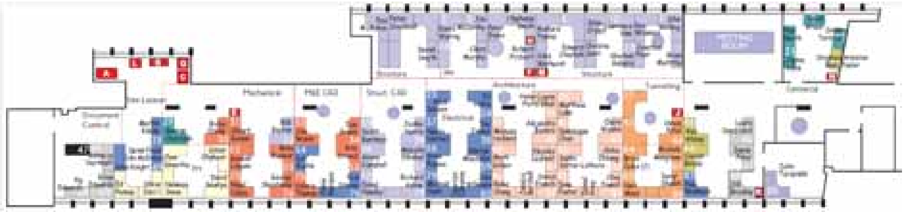

Figure 27
Layout of co-located office dated 1 June 2006 including colour-coded discipline areas and seven 'round tables'.

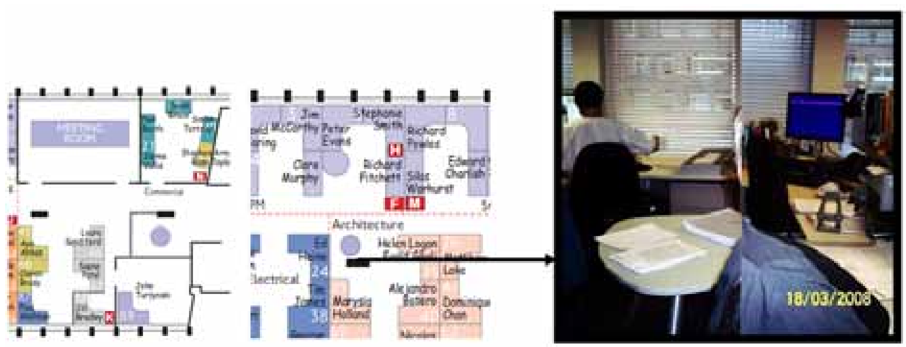

Figure 28

Figure 28a (left) Closed-off design of the commercial management crew, working space of the overall project manager and meeting rooms.
Figure 28b (middle) Official layout of co-location (2006 version) including the working space of the overall design leader and the 'conversation points' of the design crews (here that of the architectural design crew).
Figure 28c (right) Image of the programme management island taken during fieldwork in March 2008.

The image in Figure 28c depicts the common use of the discussion corners. Due to spatial limitations, the discussion corners supported designers with an extra work-surface, rather than accommodating informal interaction.

As of 2006, 89 people were working in the co-located offices. This number increased throughout the design process to 135 individuals in March 2008, based on the official update of the co-location layout prepared by the overall design leader of the engineering firm. This final number was expected to reach 151. These changing numbers represented the human capital of co-location. Co-location as the official design practice environment included both artefacts and human assets in an interactive manner due to its long-term nature. It accommodated the design activities that occur between people through their usage and the production of artefacts in order to achieve the final artefact. In intellectual properties, co-location accommodated the designers from different disciplines and different organizations representing their disciplinary knowledge, as they interacted with each other to create the final design artefact. Since co-location accommodated different organizations, it also lodged variant organizational cultures of the participants and their 'standard' design practices. Standard practice referred to the knowledge domains of organizations and the way that each organization deals with their design task. The organizations show peculiarities due to their standard practices.

Below the 'standard practices' of both the engineering firm and the firm of architects is presented.

Box 1

The Design Practice of the Engineering Firm

The engineering firm defines their design practice as "...[F]*rom perfecting the tiniest details of a building to managing complex multidisciplinary projects and developing living and working spaces for whole communities... ground breaking buildings which may not have been realised without our input...*". The firm presents itself as providing a high-quality and distinguished engineering design service by claiming 'we are different'. The firm has gained a strong position in terms of collaborating with the parties between architects and the client in order to achieve a high-quality product. They work with signature architects. In their media, a strong corporate identity can be observed as it emphasizes their interest in 'unusual' designs and collaborative design solutions.

"*...Only limited use is made of all the existing technical knowledge...with the best technical education, the designer could not hope to be familiar with* [all] *modern technical possibilities... a wealth of new knowledge, new materials, new processes have widened the field of possibilities that it cannot be adequately surveyed in a single mind. In response we must create the organisation, the 'composite mind'...*" (Official website, 2011)

The above quote that was made by their founder emphasizes the necessity of achieving shared practices ('composite mind') among the design team members by being updated with the latest technologies, tools materials which all contribute (and require) new knowledge. In their media, technology, research, and 'stated willingness' to collaborate were also the motivations as these enhance the way of working of the globally distributed teams within the company. The question that arises is to what extent were the representatives of the engineering firm within co-location convinced about this motto, and to what extent their technology and research were driven practices reflected in the co-location.

Box 2

The Firm of Architects' Design Practice

The 'standard practice' of the firm of architects in this case has been praised as an award-winning architecture and urban planning practice by Moore (1997). Their practice was awarded the 'Architect of the Year' in the 2007 Building Design Awards and has won 30 RIBA Awards (The Official Website, 2011). Moore (1997) claims the firm's practice as *"offering something quite different, a cultured, intelligent, careful, and quiet architecture that avoided the rhetoric that was postmodernism's worst vice and the dogma that was modernism's..."* (Moore, 1997; 58). In their media, the firm emphasizes the importance of the physical settings to their design processes. They attempt to reflect the designing of the environment onto their knowledge sharing practices. They describe their main office (designed by the firm) as a means of sharing the design information, allowing the designers to observe different design processes such as concept preparation, model making, and detailing. The ground floor was designed as a multi-functional space for informal meetings and displaying drawings and models. It served as well as a venue for lectures, exhibitions, film screenings, and concerts. The layout of the firm of architects suggests the use of an open environment in which the employees can participate in the design process even though they are not officially involved. This participation is through the open environment in which various phases of various projects can be observed by the employees. The multi-functional ground floor is an interaction and communication area, which accommodates meeting rooms, model making rooms and the café, where informal and social interaction takes place.

These statements and the planning criteria of their own office space suggest that there is a significant awareness of the importance of physical settings, since the firm of architects attempts to use these settings as a means of increasing both the passive and active knowledge sharing processes within the organization. The passive process is conducted while acting as a participant in the environment, someone who is able to grasp the project discussions while model making, or someone who is able to see the visualised design concepts while attending a design meeting on the multi-functional work floor. The active knowledge sharing process can be found in the informal interaction spaces such as the café, as well as during informal/formal meetings, etc.

§ 3.6.3.2 Tool-use in Co-location

Co-location contained a range of tools that facilitated those involved in the design process. The tools comprised software packages, 3D/4D models, communication and interactions, project repositories and Knowledge Management Systems (KMS).

The 3D/4D models belonged to the project management company that facilitated the intra-client team interactions. The software packages were targeted at design representation, design repositories, and distant interactions. Due to the standard of the client team, the software package for the design representation was set as Micro Station. This was set from the onset of the project in order to avoid conversion problems in the data exchange. For the repositories, software was developed by one of the designers from the tunnelling crew in the midst of the project. This software was used to control the official design submissions such as design deliverables to the client team. Beside these shared tools, each organization had its own individual system to document the project data and store the information exchanged between parties. The engineering firm used a knowledge management system to document project data as well as to facilitate intra-organizational knowledge sharing. This system included the dimensions: people, essentials, insights, and projects. The people category consisted of a personal profile page that describes the expertise, the projects involved, and the communication channels across the members. The essentials category was where generic project information could be gathered and retrieved (i.e. the regulations for heritage buildings, communication procedures). The insights category was treated as the most crucial input of the employees, since it included the feedback from individuals in specific projects with certain conditions (i.e. the reflections of the practitioners on particular subjects/ projects or a challenge faced in the projects_).

The engineering firm allocated 10 hours per month to the employees for increasing the contribution to their knowledge management system. This was an incentive to connect employees with the use of the KMS as well as to provide the inputs to the KMS. Meanwhile the Knowledge Management department conducted research within the companies or in the projects in order to monitor the use of the tools implemented in the company or e-mail efficiency, etc. Furthermore, the designers usually used e-mails and phone conversations for communication between both co-located and non-co-located team members. The Document management crew was in charge of supporting the tools for designers in co-location. This crew included four individuals who ensured that everyone worked on the same version and the file transmissions were done without any problems.

The co-location lasted eleven years, with the continuous participation of the two design team organizations; the engineering firm and the architectural firm. Throughout this eleven-year period, the client representatives periodically joined the co-location. In 2010, co-location was closed down following the termination of Phase 2 of the project.

§ 3.6.4 Case 2: BIM as a Tool-oriented Approach

Case 2 was selected to serve as an example of a tool-oriented approach that had been implemented at an inter-organizational level. Case 2 represents a bottom-up strategy that was initiated by a draftsman from the structural engineering design crew. The 3D model developed by the draftsman had different intentions. By creating this model, the design crews aimed to deal with the constant stream of design changes required by the architectural design crew. In addition, the crews were then able to view the recent status of the design during its downscaling process. As the initiating actor, the structural crew had planned that the 3D model would integrate all the design disciplines into one model so that the design changes could be performed during the downscaling process. This was a design modelling process (modelling the design in 3D based on the multi-disciplinary design information). By using a digital and interactively built 3D model, the structural engineering crew planned to manage design changes, and gain a better understanding of the other organizations' design solutions.

The 3D model was initiated during the final design phase. The draftsman was transferred from another project (a small-scale project) in order to support the structural design crew. The previous project carried out by this draftsman who used a 3D modelling software package within a project called 'Sebeka'. Due to his previous modelling experience, the draftsman proposed using the 3D model in Case 2. At first, the response from the lead structural crew regarding this proposal was not positive. However, the draftsman took deliberate action to start a 'side modelling track'. In this track, he used the support of an intern with whom the draftsman had worked on visualizing the official design deliverables submitted to the client. This side track was not part of the official design process used in Case 2. The draftsman modelled the design based on the input received from the official deliverables. This was an initial visualization in which the different disciplinary design objects overlapped. Yet, there were significant mismatches detected, in particular between the architectural and structural design solutions. These mismatches in the initial model served as a motivation for the lead designer to use the 3D model in the actual design process with other designers. Once this decision had been made, the 3D model could be initiated as a tool-oriented approach to be used throughout the design process. The draftsman's remark below illustrates the way that the 3D model was introduced to the case 2.

"*...I guess it was the first or the second day he [the intern] started, [and] discovered that there was one column and that column did not continue... That was the breaking point... After having been involved in the preliminary design, there were a lot of changes, and the second preliminary design* [called pre-Definitive/Final Design] *we thought maybe we would finish by the end of the month. The second preliminary design was a more revised design because the client had a lot of special requests; the architect changed a lot of things, so we had to redesign a lot of issues from the first preliminary design...*" (Draftsman, 2010)

This quote exemplifies the motivation behind introducing the tool, as excessive redesign work that occurred in between the design disciplines. The quote highlights the design work taken over by the new engineering firm and the re-design that occurred as a result of this hand over.

The 3D model focused on digital technologies, which dealt with the design process of actors involved in the project. It attempted to support the distant interactions of actors in order to visualize the design knowledge in 3D and to bring a synchronous process to the design environment. The 3D model-supported design team also used face-to-face interactions to discuss design problems, develop design solutions, and reflect their understandings based on the distantly exchanged design objects. The design team used short-term physical settings for face-to-face interactions such as design workshops and design meetings. These face-to-face interactions formed the essential component of the design process. In addition to organizing these face-to-face interactions and the 3D model itself, there were additional tools that supported the actors during the design process. Below, the tools used and the people involved in the 3D model are described.

§ 3.6.4.1 Tool-use in the 3D Model

In Case 2 various tools were used to support the design team. These tools included the 3D models (as there was more than one 3D model), distant communication and interaction means such as e-mail programmes and Skype, and company intranets.

As the core part of the strategy, the main function of the 3D model was to integrate disciplinary information and to visualize the design in 3D working space. The 3D model was developed based on the Bentley MicroStation software package. It was used to provide up-to-date design representation. However, only the structural engineering crew continued to use the model. Besides the structural crew, other disciplines, irrespective of which design organization they belonged to, did not change their own software during the course of the design process. The architectural firm and HVAC design services continued to use AutoCAD because the design was in its final phase and the architects had already detailed their design in 2D using AutoCAD. Figure 29 illustrates the architects' design deliverables and their working space in 2D.

Figure 29
Design representations of the firm of architects using AutoCAD

Since the other actors did not participate in using the 3D model and designing in digital 3D, the structural design crew did not change the format of the official design deliverables. The crew kept preparing and sending these deliverables in 2D format, although they had worked out the spatial design in 3D. This was because the rest of the design team were still working in 2D. The structural design crew produced 2D outputs from the 3D model as these outputs were called 'extractions' (see Figure 30). Due to the poor quality of the 2D extractions, the structural engineering crew needed another round for the elaboration of the deliverables. This elaboration of the 2D extractions was necessary in order to hand in the correct design deliverables. In the end, the 3D model was used to obtain extractions that could serve as a basis for detailing the design representation (i.e. specifying names of places, dates of submissions, measurements, axe-definition, etc.). However, this model was only accessed by one entry at a time. Therefore, the model depended on having one individual who was responsible for modelling the design based on updated information in each division. Subsequently, the structural engineering crew (consisting of roughly ten individuals dependent on one draftsman) had to update all of the design information. In order to avoid possible lags between other design disciplines, the lead designer decided to update the model as soon as the design information exchanged was certain. The 3D model was frozen periodically because it was necessary to wait until the design crews had found final design solutions for problems, before the structural engineering crew could apply the final solutions to the model. Meanwhile, the designers simultaneously worked on the 2D extractions as they manually updated their divided task and interacted with each other.

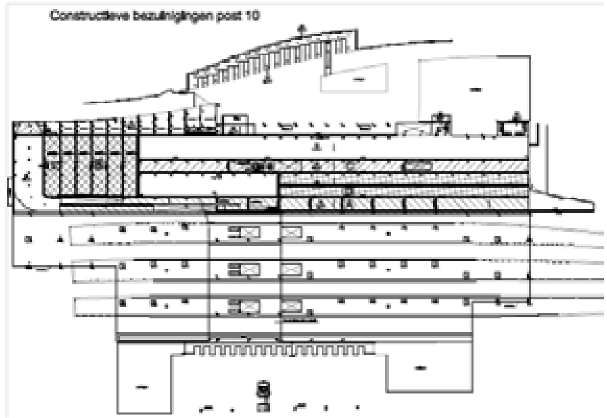

Figure 30
An example of a 2D design deliverable of the structural engineering crew by using the 3D model

In addition to the 3D model and the different software used by the architecture and HVAC design crews, two other 3D models (one was a BIM) were used in the design process. The firm of architects also hired a visualization company for modelling the design in 3D and preparing various 3D visualizations. These 3D visualizations were for presentation purposes and did not contain detailed project components (e.g. walls, floors, etc.). Except for several partial visualizations, the architects did not share this 3D model with others. The model was not used actively for the actual design activity, and it only provided static representations of the design.

Another model was a BIM driven by the client. Shortly after the structural engineers had developed their 3D design model, the client hired a company, *3DBlueprint*, to create another 3D model. This model was meant to detect clashes between disciplinary solutions. The client then asked the design team organizations to update the design based on the clashes identified. The design crews of the organizations updated the design individually using their own design tools (i.e. the architects updated their 2D drawings, whereas the structural engineers updated their 3D model). Similar to the 3D model required by the architectural firm, the client used the BIM to provide snapshots of a particular situation. Neither the client nor by the design team organizations used BIM throughout the project. The BIM ended up as a mere clash-detection tool and only provided a one-time insight into the design team. Although this case served as an example of a tool-oriented KSS, the design team interactions consisted of face-to-face interaction that took place during meetings and design workshops across the various organizations involved in the project.

In addition to the design modelling tools, the interactions among the design crews were mainly based on digital technologies, since the design team organizations were based in different locations. The main distant interaction was through email and telephone calls, or a combination of the two. In addition to these, the structural engineering crew used

Skype in virtual design dialogues with the crew members. Skype was used in a particular case where structural designers had an outsourcing company in India. In other words, the structural design crew had used extended team members who worked in India during the project design process. The crew in India was responsible for the process of elaborating 2D extractions used to make proper design deliverables. The crews in the two countries communicated via Skype and interacted virtually through desktop sharing. This enabled crew members to point out issues in the drawings and simultaneously interact and respond to these particular issues. The members who interacted via Skype used headphone sets to interact verbally as they sketched together. This way of using Skype was only observed between these two distributed crews. Although the other organizations were also physically distributed, they did not use Skype in this manner for combining verbal conversations and graphic interactions.

For the design crews involved in the project, there was no special interactive tool facilitating the distant interactions of the actors. Through e-mails, actors informed each other about decisions and agreements made by others and they used emails to officially capture decisions. E-mail messages included attached files that illustrated the design problem or design solutions regarding the context of the design issue. These attachments varied from hand-drawn sketches to partial 3D illustrations that had resulted from the 3D model. Approximately half of the email messages included at least one attachment. Even though the emails facilitated inter-disciplinary interactions by providing the content, the number of emails sent was a most problematic issue in the design process.

"*...Well we experienced a certain moment when there was a problem because I got lost in the emails. Because each person addressed questions directly to me and at a certain point I had ten emails a day just from the structural engineer about the parts of the building that they wanted to a solve....*" (Project Architect, 2010)

"*...Well, my mailbox is always full. I cannot even clean it up. Sometimes I cannot send anything anymore and then I have to clean it up. It's the culture of emailing, but I think that it also applies* [The Engineering Firm 2] *to us,* [ProM] *to everybody, everything goes by email, everything is being fixed, trying to get assurance, like: "I asked you, why you didn't answer yet?"*" (Project Leader of Conditioning, 2010)

Both actors' statements display the number of interactions as well as the cultural differences revealed during distant interactions such as a "culture of e-mailing." Actors used e-mails to capture decisions and to record the agreements made in writing..

As one of many of the tools used, the actors also organized events in which face-to-face interactions occurred. These events were targeted at 'people' and brought them together in the same physical setting. These settings, in which people discussed the design problems in order to reach shared solutions and to overlap their design objects, are described below.

§ 3.6.4.2 People in the 3D Model

Although there was a 3D model and a 3D visualized design object in the design team, the actors in Case 2 periodically organized physical settings for face-to-face interactions. These settings were meetings and design workshops for discussing design problems face-to-face. The settings were organized by both the design and client team organizations. The meetings were held at three levels: 1) client 2) project management and 3) design.

The client meetings were scheduled to serve three different levels: the steering committee, directors' meeting, and the leaders' meeting. These meetings focused on aligning the interests of the stakeholders and the projects' sponsors. The steering committee meetings were held, as a rule, once every six months. These meetings were internal and aimed at discussing the sponsors' and the stakeholders' objectives. The directors' meeting served to mediate between the steering committee members and the leaders. It was set up to ensure that the client objectives were transferred to the leaders, who represented the operational level within the client team. The leaders comprised various departments of interests within the client organizations and the leaders were responsible for providing the requirements and regulations of their departments. The directors were the actors who synthesized these requirements and regulations, combined with the steering committee's objectives (such as the scope of the project), and these were translated to the design team during the management meetings. The representative of the project management body for the client team, ProM, was in charge of the management meetings with the design team.

During the management meetings, the project manager of the engineering consortium, the architectural design leader, who served as a design coordinator, and the project manager from ProM, exchanged information about the current design object in relation to the project scope and aims. Changes to the design criteria were formulated at this level. These changes were passed from the steering committee members to the project managers of the design team. The content of the management meetings included the project scope, the budget, and project planning. With the exception of the architectural design leader, the lead designers of the other engineering disciplines were not present at the meetings. The design information gathered during these management meetings was transferred via the overall project manager of the engineering consortium to the engineering design leaders. The design team meetings were organized to include different disciplines, and took place for the most part in the architect firm's office.

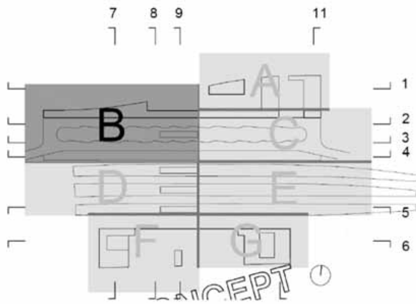

Figure 31
Division of work along design deliverables

The design meetings were divided into two types: integral design and engineering design meetings. Integral design meetings included the client representatives as well as the design leaders and the project manager of the engineering consortium. In the engineering meetings, a maximum of three knowledge domains were brought together at once. In these meetings, the actors were involved in co-design activities. The selection of the participating domains was quite ad hoc and the content was organized according to the division of work (see Figure 31 for division of work). The division of work not only determined the structure of the meetings, it also determined the representatives of the domains. Each domain had its own designers working on the divisions, and these designers engaged in face-to-face interactions with the other disciplines working on the same division. In addition to the participants, the frequency of the engineering meetings was irregular as they could be held once a week or once a month. The design meetings were held at the architect's office simply for practicality's sake since it was centrally located.

During the meetings, the participating actors brought along their design objects in 2D format. The actors worked together on the 2D drawings, and they represented their solutions or raised their problems by using sketches and drawings. Occasionally, actors shared the sketches produced during the meetings. One rule that applied during the meetings was that each actor was to take minutes (to report back to their divisions) in order to record the design decisions made. As a post-meeting activity, the architect's firm was responsible for the minutes, since they acted as the design coordinator. The firm usually defined the agenda for the next meeting by comparing the progress of the issues discussed in the previous meeting. Moreover, this agenda was exchanged among the participating actors before the meetings were held so that the actors could respond to the proposed agenda and add any points they might like to make. In this process of exchange and response, the styles of the minutes taken by each actor during each meeting varied.

The minutes consisted only of texts, without any supporting sketches in the appendices. The minutes were structured as follows: A heading including meeting title, type of meeting (either a design or managerial meeting), meeting date and location. It included a list of the participants and non-attendees. This general information heading was followed by a short description of the divisions of work. Each of these had a pre-determined time-slot. The design leaders were expected to attend all the meetings, whereas the designers representing their division only attended when it was their allocated time slot. Via the minutes and the agendas, the participants were informed of their own time slots. The minutes described the comments, decisions, and design tasks for all the divisions.

The design issues and tasks were discussed and delegated during these meetings, and both could be tracked and traced using specific numbers. Text highlighted in red print and in italics displayed the current design task being discussed. The tasks identified during the meeting were coded in black. However, the design task number remained the same. The actors responsible for the tasks were identified by their initials. Except for the identification of design tasks and the actors responsible for these tasks, there was no time frame or no deadline for informing the participants and their design organizations about the upcoming deadlines.

As intra-organizational interactions, the design organizations had different features. The firm of architects did not organize any follow-up meetings to transfer the decisions and discussions that had taken place during the design meetings. This mainly concerned the size of the architectural crew, as it was often the case that one individual worked for one division, unlike in the case of the engineering firm. In particular, the structural engineering crew consisted of approximately eleven members. The structural engineering crew was always represented at the inter-organizational meetings by the same four individuals. After each inter-organizational meeting, the lead structural engineer held an inter-disciplinary meeting (post-inter organizational meeting session) to share what was discussed with the other actors. This meeting was organized to gather the remarks of the designers who had attended the meetings and to obtain the comments of the crew members who had attended the inter-organizational meetings. The structural design leader used this session to distribute new assignments and define the milestones for the crew's deliverables. The meetings were held within the open office of Engineering Firm 2. Besides the structural engineering crew, the other engineering disciplines, which consisted mainly of the HVAC crew, did not hold regular meetings following the design meetings, although the number of crew members was equivalent to that of the structural design crew.

This reflects the way in which the actors were involved in face-to-face interactions and how they dealt with the physical settings in relation to the disciplinary and inter-disciplinary design processes that highlighted the differences between the organizational practices in the design team of the second case. Below, the standard practices of the two main design disciplines are summarized. Their practices are important when discussing the knowledge sharing processes of the actors and they reveal the extent of knowledge sharing processes of the actors through the support of tools.

Box 3

The Firm of Architect's Design Practice

The Case 2 firm of architects is an award-winning practice with a nation-wide reputation. The firm does not use media for exposing their design practice and how they approach the task of completing their projects and interacting with other parties. The firm works within 2D format regarding design representations and is well known for paying great attention to the details of the project. The interaction channel with the other parties and any party outside the firm is done through one single e-mail account. This account is exemplified as 'the firm of architects@the firm of architects.com'. The firm used this account for any interaction that took place with the design team organizations involved in the Case 2 design process. The lead architect is personally involved in each project design, and within Case 2 he was involved in each decision. The size of the firm changed periodically, yet it was never more than twenty individuals.

Box 4

The Design Practice of the Three Engineering Firms

The consortium of the three engineering organizations was represented by a project manager involved in the interaction with the other organizations such as the firm of architects and the client team. The project manager was responsible for the agenda (defined by the objectives) of the consortium organizations. The design team members referred to him as ***'the spider in the web'***. Below, the project manager explains his role in the design process.

"*…I steer the whole process. So I talk to the client about what needs to be done and divide this between the partners and assure that an integral design is developed in collaboration with the other actors, especially the architect*" (Project manager of the consortium, 2010)

The project manager's quote above highlights the responsibility of interaction between the different parties and gathering the input to the design team so that 'an integral design' could be achieved. This refers to gathering design information and holding discussions at the various levels (the management level of both the design team organizations and the client team) and this is conveyed to the design team leaders so that the leaders can pass on the information exchanged and so that the design crew members can apply the decisions taken to their design processes. Between the meetings, the design information is exchanged via telephone calls and via e-mail messages.

4 Empirical Data Analysis I: Barriers against Knowledge Sharing Strategies in Large Complex Building Projects

§ 4.1 Introduction

This chapter presents the analysis of the two case studies with regard to the first research question, the nature of Large Complex Building Projects (LCBPs) and their challenges in terms of knowledge sharing. This chapter aims to improve understanding about the challenges of LCBPs, and it shows how the design team actors of the two LCBPs experienced knowledge sharing processes and problems. Firstly, the challenges of LCBPs for knowledge sharing as reported in the literature are addressed. Secondly, the data analysis is reported to present the extent of these perceptions in the context of LCBPs. The research question addressed in this chapter is:

- What are the characteristics of large complex building projects (LCBPs) and in what way do these characteristics present barriers to knowledge sharing?

§ 4.2 Challenges of Knowledge Sharing Strategies in Large Complex Building Projects

According to the literature reviewed in § 2.4.8, large complex building projects present particular challenges for designing and implementing knowledge sharing strategies. Three reasons are normally given for these challenges. Firstly, large complex building projects are seen as unique, which presents a challenge for knowledge sharing, as each project has a design task that is accomplished by organizationally, socially, technically unique design team. Secondly, projects are limited in time, which can present a challenge for knowledge sharing if the fixed duration is seen as insufficient time to create a culture for knowledge sharing. Thirdly, the complex nature of both the design teams and the design task of large complex building projects is presented in the literature as a challenge to design and implement knowledge sharing strategies. The purpose of this first analysis is to investigate if these assumptions actually hold. The analysis will address the following three questions become important to be answered.

1 What makes large complex building projects unique or do they have any generic features?

2 What are the implications of temporariness in large complex building projects?

3 What makes large complex building projects complex and how do design practitioners handle this complexity?

§ 4.3 Uniqueness

The two examples of LCBPs were unique in many aspects but also showed similar characteristics. In both cases, project members (design team members, client representatives) perceive their projects as being unique. However, as we will see, they experienced similar challenges. Table 4 summarizes the generic characteristics of each case.

Unique in Case 1	Unique in Case 2	Common
A. Client structure		
An 'unusual' role of public organizations "first time in the company's history" – direct involvement	A collaborative role within a unique set of relations amongst various organizations from different fields of expertise	New roles within project-specific context New responsibilities in company's context Roles and responsibilities were not unique in particular in other organizations, projects
B Stakeholders involvement		
National Heritage Institute Traffic management (station remained in operation during reconstruction: bus, tram, roads) Other stakeholders for the neighbouring investment projects (both the railway projects and the connections that Case1 had to provide)	The consortium between National Railway Bodies+ Municipality of the City+ The Ministries for Environment and Spatial Planning, Housing Associations, the Tenured Tenants for Office and Commerce Areas	Variety of stakeholders in both cases Variety of conflicting interests during the course of the project Long chains of commands Diverse but evident procedures to adhere to, no sets of surprises, no project-specific procedures or authorizations

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Unique in Case 1	Unique in Case 2	Common
C. Geographical Location		
Existing underground needs to be run Neighbouring historical monuments	The position of the project within regional development	Location as 'constraint-creators' which is typical for building in cities Not the nature of locations but the types of problems of location are generic (see the stakeholders)
D. The Nature of Design and Design Strategies		
Phasing the main project and subcontracting different phases, then dividing the sub-projects into different teams through the problematic parts (i.e. the [heritage] curve, ticket gates, the [X] lights, etc.)	One building with multiple functions integrated –decomposing the 'one' into four theme (i.e. housing, commerce & offices, parking, tunnelling)	Generic ways to approach the projects like division of work by decomposing the project to be more manageable to make it less 'unique' and more familiar Meetings/workshops to recompose the divided project parts

Table 4

Characteristics of each project in terms of uniqueness and generic features

§ 4.3.1 Client Structure

The first characteristic is the client's perspectives in relation to their organizational structures. Both cases represent different organizational structures that resulted in similar problems regarding their client structures. Case 1 was financed by the government whereas Case 2 was funded by a consortium. Their relationship structure and formation of the organizations was unique, but not their role. Both clients represented the same interest such as representing the government's agenda that changed as a result of market changes, political changes etc. So the specific set-up of the client teams was unique yet their changing agenda that resulted in changes in the design process was generic. Besides the role of representing the governments' agendas, the roles of the client team were generic in both projects. As an example, the underground body's involvement was not unique, although their 'standard' practices in Case 1 was. The public body was founded to manage and direct both existing and new underground stations. According to the statement of the department representative, the selection of the underground body was due to their standard practice.

"… [the Underground Body] *is the operator and has been appointed by the department to build the station, expand the station. It would be stupid to give it to another company than them…*" (Government Representative, 2008)

The Ministry of Transport, on the other hand, "*was the main stakeholder that pays for the project*" (Government Representative, 2008). Their standard organizational practice was to deal with projects and they were set up as the agency for nationwide transport. Yet, in this project, the department of the ministry played an active role in being involved in design decisions, as opposed to their standard practice. This was a unique role for them to play; a representative of the ministry stated the following in regard to this role.

"*...This project is extremely unusual. It is not normal for the department to be the direct sponsor and the founder of the development of an underground system...* [The department] *would never have an active role for this type of project at all...*" (Government Representative, 2008)

Yet this role did not require a completely new practice, but instead a combination of different existing approaches was used. This integration of other transport project agendas with Case 1 enabled the department to create the most advantageous situation for the government. In other words, this role was new, but not unique.

Unlike Case 1, the client structure in Case 2 was a consortium containing public bodies with different roles, such as sponsoring, and directing the design team technically. On one hand, this formation of both consortium and interests were project-specific. On the other hand, the motivation behind this form of consortium was due to the organizational practices required to develop such projects, and in this sense similar to Case 1. In both cases, these forms of groups resulted in conflicting interests of the client organizations throughout the process.

§ 4.3.2 Stakeholders Involvement

The requirements of the stakeholders who did not directly finance the project but who had a direct role in making the design decisions used procedures which were not unique, but which were specific to the location where the project was carried out. In each context (national, industrial, cultural), there are diverse (sometimes implicit) but evident procedures to follow. These procedures are not always uniquely designed for each project: often similar methodologies may be applied. However, uniqueness can still be found in the combinations of procedures used in order to obtain approvals and this uniqueness can also be seen in the relationship between the actors who are involved in requesting and granting permission.

The actors involved perceived the nature of the design as unique in both cases. Both clients treated their projects as one-off designs. The client of the second case selected the design through an architectural competition for its 'unique' ambition: one building for the city (the Lead Architect, 2006). Uniqueness of the design became a driver for conveyance of project. The statement of the client representative exemplifies the motivation as a unique and un-tried project from their perspective.

"...*It* [the project] *is a non-conventional, unexpected plan... progressive, non-conventional, fanciful, and guiding.... It brings up the elements and functions differently, we thought. This is not only fanciful but also guiding for this type building in future. We do not have this type of station building yet...*" (Client representative, 2005)

However, this supposedly unique solution was in fact a well-known design solution in other locations, for example in Milan Garibaldi or in Melbourne Central: a major regional shopping centre, offices, and public transport hub. Also Tokyo Central Station is merged with its surroundings and incorporates offices and shopping malls. In other words, the project was unique for the actors involved, but this does not indicate that underlying concept had not been implemented earlier. Similarly, both projects were hubs within a wider transport project and as such contained a long chain of commands; Case 1 due to a three-levelled hierarchy consisting of the government, a department and the underground body, Case 2 due to three differently structured organizations consisting of state-owned public organizations, the municipality, and the private sector for the commercial spaces.

§ 4.3.3 Geographical Location

In terms of geographical location, the sites of both projects were unique. Yet both projects did not require a unique practice invented for this type of project due to their location and programme approach, nor was it necessary for them to have unique roles of the design team members. The Case 1 building site contained unique difficulties such a web of roads, existing public transport connections, railway connections, historical buildings in the immediate vicinity, and infrastructures. Case 2 did not share these difficulties, but involved similar issues in terms of stakeholders' requirements such as the complex mix of real estate tenants - including commercial, office, and public properties. The long command chain between designers and the authorities as well as technical problems occurring in interfaces is similar in both cases.

In other words, both projects were unique due to their location, the programme required for that particular location, and the specific hub requirements within the wider transport project. However, the projects were 'less unique' than perceived by the actors, because they were not pioneering projects to be implemented for the first time. This does not mean that the projects are the replication of previous example projects. Both projects were perceived as unique, but they actually presented a combination of problems for which precedents had been set, and with which the participants had had varying degrees of previous experience. They shared certain similarities, such as in the way the projects developed their design methodologies.

§ 4.3.4 The Nature of Design and Design Strategies

The design strategies in both cases were similar; decomposing tasks and then linking the decomposed tasks. Although the designers chose different ways of cutting up the task, their approach was generic. The unique and 'large' task was divided into sub-projects to make it manageable. Case 1 was split into five metro lines to create five similar and manageable design processes. Case 2 represented a function-based division of work. The unique 'main' design was divided into five parts: block A to E. Each block had a single function, for example housing, the entrance, and offices, parking, and tunnelling.

This decomposition is not a new concept developed to overcome large projects as a complete constellation. It functions as a method to make a unique project more familiar, in order to tackle a new project based on previous experiences. However, in both cases, problems occurred at the interfaces between sub-project, and this interface problem is again very generic. Projects were decomposed to make them more manageable, more familiar, and 'less unique' but critical issues remained, such as unconnected design parts. In this last example, the interfaces projected a trade-off situation in which a design compromise occurred. The irony is that while this process of decomposition and the difficulty of putting the divided parts back together has been standard practice since the 1970s (see(Robinson 1972; Grabher 2002), in both cases the problems occurred at the interfaces. The following conversation between two designers exemplifies this interface problem:

"Can you have a look at minus one? […] Because it is already there on the right position […] I don't know if it's all from the same drawing […] Are you sure? […] Because it was at the last drawing […] It was correct at minus one […] I don't know about block A […] I haven't got a clue about block A […] I have made a remark about it… yes, wait […] Hang on… alright it wasn't exactly, can you measure the distance between A and B in your drawing? […] Sorry […] Alright, thank you." (a phone conversation between a structural engineer and an architect –Observation notes, 2010)

In Case 1, the coordination and interrelations of the subprojects was accomplished by holding meetings between designers, giving workshops to the various parties, and arranging co-located offices in which designers from different organizations worked together on a regular basis. These three different approaches were necessary to re-integrate the decomposed projects. In Case 2, the integration was achieved through different types of meetings (whole-day meeting between architects and engineers, one-hour within design crews and structural engineers). Yet unlike Case 1, the decomposition of the projects determined the meeting structure. In this structure, each function had a particular time slot when the design crew members who were responsible came, discussed the issues and left. In other words, both projects used a multi-disciplinary approach to 'connect' the individual parts of the main design and to resolve challenges related to the interfaces between the project divisions. Both projects utilized the same planning approach of setting up meetings for handling inter-disciplinary design problems organized around division of work.

Two arguments can be given for the reduced significance of uniqueness: the combination and decomposition of the problem or brief and the design method. In each case, the so-called unique project is actually a combination of established sub-projects (even partial combinations are precedent), so that which the exact combination of programmatic elements and site conditions is technically unique; it possesses a generic nature in both the constituent elements, and in the combinations of some of those constituent elements. Viewing the projects in this way allows us to progress and to establish that, whereas the project may be unique in terms of its team members, these members still have gained experience with these more generic elements and combinations.

In this discussion on the general concept of uniqueness, the way that current practices cope with the unique components of projects was elaborated and the generic characters of large complex building projects were explored. The analysis of both the uniqueness and generic-ness of projects helps to improve practitioners' understanding of how to deliberately implement strategies at an inter-organizational level regarding optimizing project management in order to control the problems that mostly occur during interrelation of the projects, for example preventing the misinterpretation of different parties' approaches.

§ 4.4 Temporality

In both cases, the temporality of the project's duration emerged as a relative concept. The Table 5 summarizes the issues related with the temporariness of LCBPs and distinguishes between perceived temporality and actual attitudes towards temporariness in two cases.

Perceived temporality in two cases		Actual attitudes towards temporariness
Case 1	Case 2	
A. Long working period; predetermined start and end dates of the project		
Total project duration (incl. design and construction) was seven years; initially set for period 1999-2006	Project duration initially between 2006 – 2008	Longer period than anticipated Ten years for design and construction of phase 1 Five years (still on-going) to deliver final design drawings to contractor
B. Temporary relationships: a challenge to invest on building cross-disciplinary social structures		
Assigning designers from their parent organization to the co-located design team, even though the co-location lasted eleven years	Conventional efforts and no deliberate implementation or even consideration of the potential problems that may occur during the process with regards to social structure	Emerging strategies and/or evolving conventional methods towards social structures Co-location provided long-term multi-disciplinary working environment by which project-specific design routine was set No evidence on relationship settings except for inter-organizational meetings (at management and technical levels)
C. Discontinuity of People		
People treated as non-temporary as they would be working throughout the project.		High turnover rate of project team members People only involved temporarily therefore it was a challenge to maintain continuity during the projects

Table 5
the differences between perceived temporality and actual temporary features of projects

§ 4.4.1 Long Working Period

Both cases represented a long period – namely, an entire decade had elapsed between initiation and finish of the project. In this period, design teams were formed and they worked together towards the main goal, which was to accomplish the projects. The time period in Case 1 was thirteen years: the initial go-ahead was given in 1996 and the project was completed in 2009. Case 2 was initiated in 2004 and was expected to be completed in 2012. Thus, this includes a duration of 8 years, whereas in the original planning documents, it stated that the tender, appointing the contractor and completing the project would take three years. Nevertheless, the final design through which the contractor was to be selected was, after three years, still an on-going process due to client-driven scope changes.

Similarly, in Case 1 the initial planning set 2006 as the project completion date, so there was a three-year lag in achieving the original plan. In both project timelines, it emerged that project processes took longer than anticipated by actors. Figure 32 illustrates the actual timeline of the two projects whose design processes (in Case 2 including construction) have taken decades.

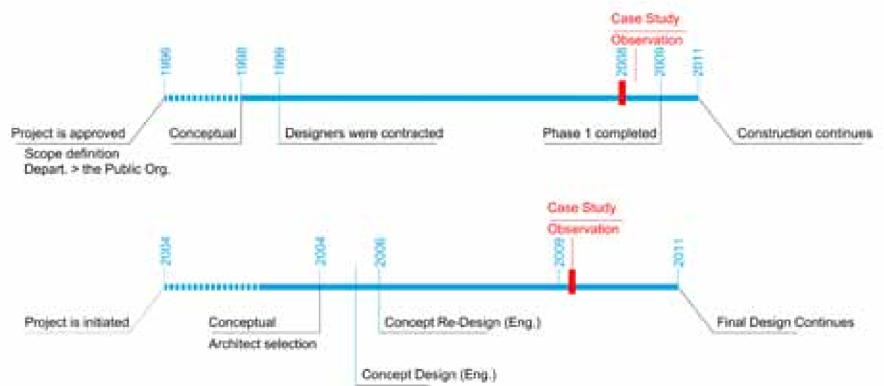


Figure 32
Timeline and important milestones of Case 1 (above) and Case 2 (below) (© Bektaş)

§ 4.4.2 Temporary Relationships

The second issue that emerged was that of temporary relationships. The temporal nature of projects was said to pose a challenge when creating social structures that form the infrastructure for knowledge sharing. Due to the perception of the projects as temporary, no investment, and resource allocation was made to increase the social relationships between the parties. Yet as discussed in the previous section, temporality is actually a misperception in LCBP. As a result, in both cases ad-hoc implementations had to be developed to foster building social interaction and relations, which could have been anticipated if it had not been for the misperception of the projects being 'temporary'.

Case 1 included a co-location strategy to bring the individuals together in order to break down the disciplinary barriers and promote the interaction among the disciplines (Kahn et al. 1997). The goal was to create long-term commitment among different parties by bringing actors together in the same physical space. Co-location was initiated in 2001 due to the large and complex nature of the project and terminated when the project was completed in 2009. It was a long-term investment in building relationships between disciplines (and organizations), as, by the end of the project, partners had been working together for seven years. During this period, closer relationships developed compared to those of the un-co-located teams. The following remark made by the lead architect emphasizes the strengthened relationships among the leaders through co-location.

"...*It* [referring to having a good relationship] *is also about co-location, yes it is a fabulous idea to bring all the people and but it is because at the end of the day it is about personal relationships and about being able to bring all the problems to the table. I think we have a pretty good relationship with at the moment, well, we* [the firm of architects] *in some respects with* [the private consortium's representative as 'new' client]... *He is generally pretty good at kind of coming and talking things...*" (Lead Architect of Case 1, 2008)

Although the lead architect was satisfied with regards to co-location, she implicitly discussed the 'personal' drivers that are required for building close relationships; both the willingness and the ability of those who collaborate. In Case 2, co-location was a long-term implementation within a 'temporary' setting to boost social relationships. Nevertheless, the implementation remained limited and did not succeed in breaking existing disciplinary boundaries. The contrast between both projects lies in the perception and the implementations. In other words, co-location – a long-term strategy - was implemented for a 'temporary' setting. While the setting lasted for seven years and as such was not temporary, it did not succeed in establishing an integrated multi-disciplinary group, since the disciplinary islands were retained within the co-location.

Unlike Case 1, there was no long-term strategy in Case 2 (neither ad hoc nor deliberate) during the design process regarding social relationship investment. The strategy adopted instead, namely meetings, was meant to increase face-to-face interaction and improve design solutions. However, the idea behind holding meetings was similar to co-location: to create a multi-disciplinary environment in which designers strived to work collaboratively. Meetings were held intermittently and were not as intensive as in the co-location setting of case 1, which resulted in a long-term and continual work rhythm. At the end of the day, this limited the relationship building between the actors as they developed a better understanding of their practices, and it also hindered them from reflecting on this understanding in their own practices.

"...*Actually it* [meeting between different client representatives within the consortium] *should be four times per year but last year they met more often. And now it is more important because now they have to get a bond together...*" (Client Representative of Case 2, 2010)

In this remark, the client representative emphasizes that the frequency of the meetings increased in order to strengthen 'the bond' between the actors. This remark, however, implies that the frequency changed over time due to the particular phase of the project.

In contrast, the lead engineer of conditioning and tunnelling emphasized the insufficient frequency of these meetings.

"...*I heard last week that the last board meeting of this year was at the beginning of the year, so that actually happens too seldom as well. And then a financial person from our division is involved, because he needs to be informed about what happens in the* [the Ministry of Housing]..." (Lead Infrastructure Engineer of Engineering Firm 1, 2010)

As well as reflecting on the number of meetings held, the lead engineer introduced the aspect of adequate representation as a requirement for information flow. The lead engineer also refers to the evolving character of the meetings.

"...*There were too few project meetings between* [The Engineering Consortium] *and* [ProM Project Management Body of National Railways]. *During Final Design, we were used to meeting once a month with* [Project Manager of the Eng. Consortium] *people from* [ProM] *and people from the municipality and* [NRD, National Railways] *and to talk about the project and the actions. And from the specification phase that totally disappeared. I have never been to meetings about the content of the project any more...*" (Lead Infra Engineer of Engineering Firm 1, 2010)

However, the meetings had different levels of ownership: project managers (client representatives, the lead designers), project leaders (technical staff multi-disciplinary), and mono-disciplinary actors (between designers and their project leaders). One issue that arose during the meetings was that they evolved throughout the design elaboration process. In other words, the formats in which the design issues were structured, the duration of the meetings, and the levels at which the issues of project were discussed (the type of desired design solutions vs. their impacts on costs and time) changed over time.

The evolution was ad-hoc and experimental. On the one hand, the project was not perceived as being 'long enough' to design and implement a strategy to increase social structures that might bring disciplinary cohesion to the project environment. On the other hand, the project process (the design phase only) was long enough to accommodate an evolution in meeting structures, time schedules, and formats due to the five-year duration of the design process. Below follow some comments that were made by the design team:

"... *If you come together, a team meeting with someone from* [the Engineering Firm 2], *then you got 10 points to discuss, and after that meeting, the 10 points...you fixed them. It is going well, and 90 percent things are good. But when you have to communicate back, you have to do it by phone or by e-mails. Then it is always diffcult to interpret the things exactly you mean it. You want it* (The Project Architect 2), *so you need a dialogue to make sure what you mean* (The Project Architect 1)...*You need conversation, you need dialogue, you need to see each other, the reactions...You need your eyes and your ears in the meeting...*" (Joint-interview with three project architects of Case 2, 2010)

Another issue that emerged from the meetings was the 'life-after-the-meetings'. In other words, the interpretation of design objects and decisions taken in the meetings required a strong cycle of interaction as well as a good line of communication. In Case 2 this became an issue, as most of the design work continued in 'disciplinary islands' where designers work individually or in an interaction with their own disciplines.

"…And I think especially in a design team there are extremely different cultures. And I think people from [the Engineering Firm 2] *and people from* [the Architectural Bureau] *think extremely differently about what the building is. So I can imagine that if you would move into one room and at a certain point say 'well let's go to those and discuss in the room', I can imagine we would understand each other better. So I can understand them because I talk and see them…"* (Project architect 2 of Case 2, 2010)

This quote illustrates the contrasts between co-location as a long term and meetings as a short-term strategy.

§ 4.4.3 Discontinuity of People

The last issue regarding the difference in the perception of temporality is about people as human capital in the design process. In both projects, the frequent staff changes and the resulting gaps emerged as a serious problem. In other words, the temporality of the projects evokes the naive assumption that those who were involved at the beginning of a project would continue to work throughout the project. Hence, not the project duration, but the commitment of the people who contributed to the project process became temporal. This discontinuity interrupted existing relationships set between the organizations up to that moment. The relations were interrupted because if someone were to leave, he or she would take both the knowledge gained during the projects, and their past experience away with them when they left.. This issue resulted in two challenges for the design team: their relationship with the client and with other designers. When the discontinuity occurred on the client's side, the challenge for the designer was to re-convince the new client contact person who now had the power to change the direction in which the design process was heading. When a member of the design team (or the lead designer) left, the internal handover process easily became problematic.

In Case 1, the client side discontinuity was extreme, since a private consortium was contracted as 'client' due to privatization of governmental bodies. This consortium broke the existing direct line between the designers and the client. Additionally, the new client representatives needed to be introduced to project progresses.

"... [E]*ffectively started with* [the Underground Body] *being our client, then it moved to* [a public body responsible for surface lines] *being our client, but they were working for [the Underground Body], and then to* [Private Consortium]...*Overall it meant that we had gone through a series of client while we were still doing the same design...*" (Program Manager of Case 2, 2008)

The programme manager's statement reveals that, while the design progress continued, the project duration was long enough to accommodate several organizational changes, in addition to his perspective towards keeping the current design process uninterrupted within a flow of client-based change.

The privatization decision was an official interruption of the normally permanent client role in the project. Presumably, changing the client in the middle of a project is more unlikely than changing other parties or individuals. This change was not a result of an economic recession or market change, but of the governments' agenda. As one can imagine, a change in a public organization in the client role would have similar consequences in any project. One important issue that emerged from the change in Case 1 was that the changes made to the client structure added to the turnover of staff.

"...*Well let me see, actually first we started with* [Jo], *he left*. [Pete] *came, he left*. [Andy] *took over, and he left*. [Mathew] *took over; he had cancer, it was terrible. And there was also a guy named* [Jordan], *he was in the middle of somewhere and then Sam, so that is up to seven, no six, and now there is a guy named* [Martin]. *So we are around the seventh person, and that is in 2 years and 4 months... So you see there was no continuity. And also there is no continuity on client side, [the Private Consortium] side either...*" (The Lead Architect of Case 1, 2008)

In Case 2, the discontinuity of the people employed was problematic in two ways: the turnover of the designers/managers and discontinuity of one of the client organizations. The first emerged as a change in the business culture; turnover of employees, particularly young professionals.

"...*The main client,* [ProM] *has people there like three years and then they say 'OK goodbye'. They go to another job, another office, all the knowledge that you have all the issues and decisions you give together, phew* [with a clap]*! It is gone! And the new person he does not know the discussions, the decisions, and let's start up again! It is very very time consuming...*" (Project Architect 1 of Case 2, 2010)

The quote by the project architect in Case 2 is in keeping with the lead architect's feelings of frustration in Case 1. In addition to the staff turnover rate, he expresses the problem beneath the high turnover: the loss of knowledge, lost track record of decisions and the need for transfer of design history (built up to that moment) to the newcomers.

In Case 1, the project was initiated in 1996. In 1999, the scope was agreed among the client organizations and the client appointed an engineering company for the full engineering service based on a concept design developed by another company. Between 1999 and 2001, the concept was redesigned due to the fact that the basic design had become outdated. In 2004, a new private consortium became involved as the 'client' due to the privatisation. In 2009, the project was completed (see Figure 33).

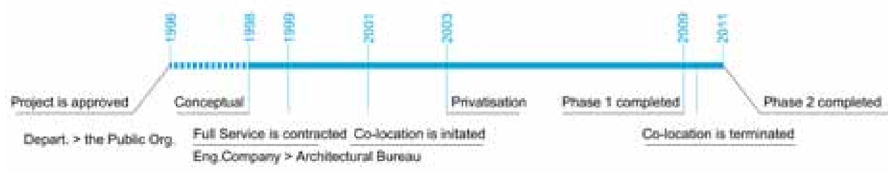


Figure 33
The Case 1 time line (© Bektaş)

In Case 2, the project was initiated in 2004 and an architect was selected. An engineering firm was appointed for the full engineering design. In 2006, a new engineering company was appointed by forming a consortium of three organizations and the concept design was renewed. In 2007, the client's project management requested a cost reduction. In 2008, a revised design was agreed upon. At the end of 2009, one of the client organizations asked for a second cost reduction of about 10% of the overall project cost. This second redesign was accomplished within 2.5 months . In 2010, the second track based on this new solution was started. In 2011, the design team was still applying the changed criteria it had received from the commercial space tenants, and the tender for building the project had not yet been published (see Figure 34).

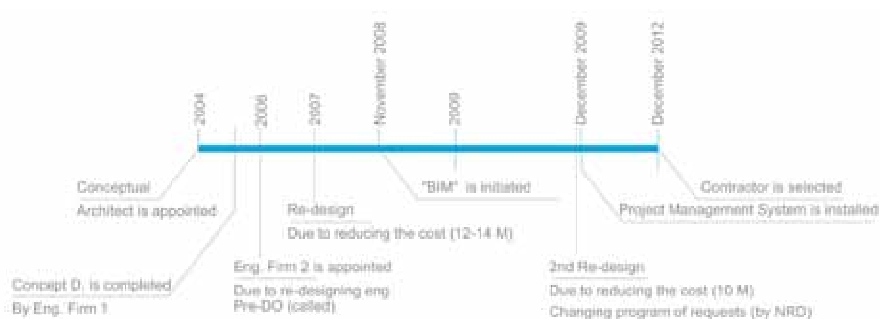


Figure 34
The Case 2 time line (© Bektaş)

In both projects, the design work was spread over many years. In the extensive timelines of both cases, two issues emerges: 1) the duration of the project was longer than assumed, 2) emerging strategies were used to enhance the social structures required to synchronize the design process as well as to come up with different design solutions. In other words, the design processes accommodated the natural efforts made due to the emerging needs of the actors, yet the timing of the implementations was problematic.

In Case 1, a multi-disciplinary office was created in which different disciplinary processes were managed. However, this only happened three years after the design process had started. In Case 2, the meetings were organized according to the needs of social interaction and the dialogues exchanged between the designers, yet these were not structured beforehand. The meetings were managed ad-hoc depending on the particular phase of the project. In addition to the meetings, a tool was introduced tool but only at a late state and it remained a premature strategy. The differences between the two projects lay in their approaches; the commonality lies in the efforts throughout the project arising from the needs summarized in Table 5. In other words, the design team members took the initiative to address temporality, which remains a mind-set problem rather than a constraint for long-term projects per se.

§ 4.5 Complexity

The level of complexity found in the projects was boosted by the radical changes made to the institutional frameworks, political and economic discontinuities, and the unstable project environment. In both Cases, the preconception of complexity was actually based on a false impression as seen for in the other two characteristics, temporariness and uniqueness. This false impression was the result of the blurred distinction between three issues: complexity, unpredictability (in the sense of fluidity) and uncertainty. Complexity refers to characteristics of the projects, such as the number of stakeholders, programme components, number of design team members, and the number of authorities. Examples of complexity introduced by this last group are the permissions required for the site, programme and function of the projects. This form of complexity lies in the nature of the design and can be anticipated in advance, enabling identification of how complex the project to be accomplished would be. If the extent of the complexity of a projects is not well anticipated, then it will result in problematic project processes.

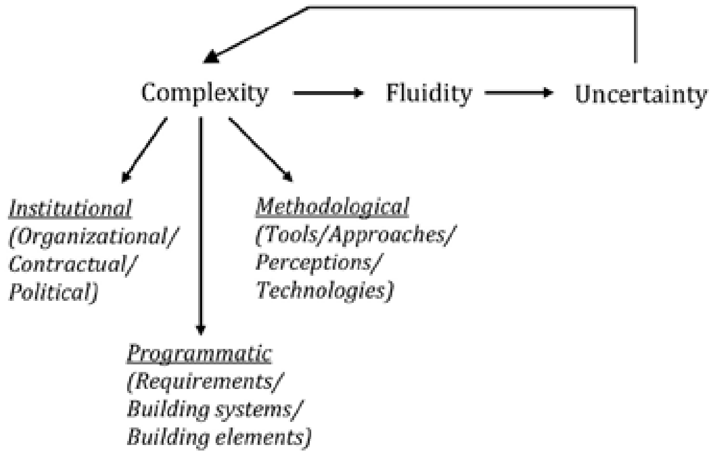


Figure 35
Interrelation of the three concepts complexity, fluiditiy, uncertainty (© Bektaş)

In addition, the time dimension brings a fluid character into such projects, since 'time' can also refer to the future, and therefore it is not completely predictable. Fluidity in projects can be caused by unpredictability in the continuity of organizations (clients, stakeholders, and disciplinary firms/bureaus), continuity of people (design team members as managers, project leaders, lead designers) and market conditions. The one common consequence is the discontinuity of decisions that leads to an uncertain project environment (see Figure 35).

§ 4.5.1 The Organizational Structure of the Client

The first issue that emerges is the structure of the client organisation as a dimension that adds to the complexity. It is about the capacity to manage the different demands of various organizations within the client structure, which leads to complexity and makes projects difficult to manage. When the client fails to predict certain 'roadmaps' in the project, and when the client does not take the project agenda into account, severe consequences become unavoidable such as excessive re-designs, cost overruns and delays. The main reason these problems occur is due to changes in project scope.

The Transportation Department of the Ministry and The Public Underground Body had a three-year period to negotiate the scope, responsibilities, and the legal agreements. This meshing of scopes was necessary in order to find the best way for the government, yet it involved a fluidity of design decisions. The following statement exemplifies the motivation behind this scope 'mesh':

"...*We told* [The Underground Body] *they would have to change the design to better mesh with* [The Public Railway Body as the client of the Railway Station]. *So we changed the scope to have that happened. So we spent long time with* [The Underground Body] *and* [The Railway Body] *to redefine the scope of phase two...*" (Client Representative of the Ministry of Case 1, 2008)

This statement refers to a dynamic process of scope as well as the design process. In other words, the requirements of the initial client became fluid and multi-faceted due to the interrelated projects. In the following quote, the client representative acknowledged the fluidity of their scope, something that the client team had not foreseen.

"...*I don't think we realized when we started how fluid the design was going to be, how fluid the scope of the project was going to be, and how frequently we were going to undergo clients-driven design refinements....*" (Client Representative of the Ministry of Case 1, 2008)

This resulted in an instable scope on which design team members needed to work. In other words, there were two parallel dynamic processes; scope integration and design elaboration to which the complexity of a changing scope was applied. Below the client representative comments on the complexity that the scope changes brought.

"...*I never worked on one that has the complexity in political and strategic issues and the fluidity of the decisions. There were a lot of major factors where we have probably made strategic compromises in order to try to marry different objectives together. Which I am sure when looked at from the designers' level,* [they] *are incomprehensible. They would not understand what something has changed; something they may have thought that it would work effectively to something they make and work less effectively... Nothing is perfect and you have to accept some 'worsening' in one area in order to get betterment in somewhere else. And the designer won't be able to see that...*" (The Client Representative, 2008).

The quote illustrates complexity as caused by political changes. The initial client had responsibilities at a different level than the public organization (Underground Works). The designers, on the other hand, had limited interface with the political and institutional concerns. The decision to change the design and to align the process with other projects came from above.

The statement contains some inconsistencies regarding the predictable and unpredictable natures of the projects. On the one hand, different public companies are involved, for instance, the clients of the various transportation projects. The unpredicted issue was the potential need to link the railway and underground stations. Perhaps in the initial project agenda, this was not a priority. But failing to predict the future connection between transportation projects is an obvious lapse in the vision behind an urban 'vehicle' project of this nature. The scope integration was indeed complex, but the problems occurred when trying to find a harmonious way of working with all the relevant transportation projects. Hence, the complex nature of Case 1 ended up being difficult to manage as the Transportation Department of the Ministry did not anticipate the need for this integration in advance. Case 1 finished as if it was a part of one tentative 'mega'-complex project from the government's perspective, since the projects regarding particular transportation problems were not considered individually within their own context. Therefore, the complexity of scope was multiplied by the integration issues. In other words, although the Department played an active role in the design process, their roles and responsibilities comprise a helicopter view over all running and planned transportation projects. In other words, the Department of Transportation responsibility included being aware of the fact that their transportation web was formed by all of the transportation projects, both in underground, railway, and other forms of transportation. Therefore, the department should have estimated the scope and integration of both the railway and underground projects beforehand in order to end up with a more manageable project process. Case 1, therefore was a good example of a fluid project process since the project accommodated institutional shift –privatisation, as well as the responsibility of the Department – meshing the transportation projects. Both features made the project process difficult to manage.

Privatisation, on the other hand, is not a sudden implementation. It involves a process in which handover details are elaborated, contractual agreements between potential organizations and the client are prepared, and a tender is made. Yet the effect of the privatisation on Case 1 appeared to be unplanned. This institutional change (from public to private) resulted in a new scope from a new client. The criteria were renewed by the new client, who required a new design that would respond to these changes. The private organization's focus was on the operation of the station, and this conflicted with some of the initial client concerns such as maintenance.

"*…If something new gets inserted in the middle, and has to fit in and has completely different objectives to the previous assessor…So cohesion was very problematic because* [the private Consortium] *came with completely different agendas…*[The Private Consortium] *has an objective to make a profit and to take a limited risk it is a very different balance to a public sector organization…*" (The Client Representative of Case 1, 2008)

The client representative's word choice draws attention to a 'non-fit' of the private client's agenda with that of the existing project. This would eventually lead to a major design conflict between the new client and the existing project team as the 'old' client and design team members had reached several consensuses on the project's design development. Hence, expectations regarding the project were changed. In addition to the change in scope, the new client structure broke the existing chain of command between the designers and the initial client organizations, and it severed the direct relationship between the public organization and the designers. The problem was not the increased number of organizations acting as client, but the new dynamics such as input into the project process. These new dynamics (new people, different working methodologies, finance-orientation, scope re-definition) brought instability to the existing project environment.

"...*This* [privatization of the Underground Body] *was just a component of it so you know we had to accept that and work with it. But I think if you are looking at this as fresh I would not choose to restructure* [the Underground Body] *at just the time we try to specify and deliver a major project. That to me was the fundamental way in which* [the Underground Body] *was restructured. At just the time we needed stability and a central focus...*" (The Client Representative of Case 1, 2008)

In Case 2, different problems arose from the client structure: increased demands made by the financing bodies and an insufficient brief. Unlike Case 1, the multi-faceted client nature essential to finance the project, resulted in a fluid project process. But as in Case 1, there were major changes, which resulted in re-design. This is a common consequence although Case 1 required three years to negotiate the scope period. Case 2 was blamed, as there was only a question list from the client and no program of requirements. In other words, the fluidity of decision, organizations, and market conditions had an identical consequence in both projects; scope redefinition leading to redesign. Since in Case 2 the project was initiated by a consortium of The National Railway Body, the municipality, the Province, the Ministry of Transportation, Public Works and Waterworks and the Ministry of Housing, Spatial Planning and the Environment, the change of interest and change in market conditions could not be seen as a surprise in the long run. Yet both problems were perceived as a surprise. The changed market condition and the influence of the economic recession on the design are stated in the following quote:

"...*The office market went down and everybody says ok, housing is ok, and now housing just stopped, just stopped. Even though you have a great design, it just stopped...It is crazy now. So everything changed. That means that also changed one of the partners. And that is* [NRD, National Railways]. *They said we should start being a real Real Estate firm. 'Oh what does it mean?'. For example, we want to make profit. 'Oh, OK. Profit? We never make profit.' And then you know, because the Ministry of Finance, the owner, the state owner let's stay, they said 'well we would like to have profit from you, so be professional'. Then they start to say 'OK* [Case 2] - *No, we should not do this anymore...*" (Client Representative from ProM, 2010)

The statement above exemplifies the change in market conditions and in the interests of the client organisations in the midst of the project. This change led to the demand for a different design path from the designers in order to make the project more profitable. However, the influence on the design process was similar; the changing scope and changing design philosophy both resulted in an immense amount of re-design effort, but not in the re-design of the scope. In both cases, the client changed their requirements during the project. In 2007 and 2009, the project faced client-driven cost reductions of about 10m euros. These cost reductions resulted in two re-designs. These changes resulted in two contradicting perspectives: that of the designers and that of the client representatives. The designers claimed that there was a lack of accurate scope (mainly referring to the program of requirements); the client stated that there was a lack of synchronic design methodology. The scope problems resulted in the demands of the client not being clarified so the project became fluid. In parallel, a project re-design was attempted with the aim of reducing the cost of the project by approximately 14 m euros. The architect and the engineering consortium researched the design alternatives and reduced the budget by 10 m euros, yet the decision remained unclear. A second scope reduction was introduced into the project agenda in 2009. This time the reason was that the vision of one of the public companies involved in the client consortium had changed. The following statements highlight the frustration behind these re-designs in relation to the view of an unclear program of requirements.

"…*Slowly,* [National Railways, NRD] *has the same type of shops at all stations. The demands of these actors are slowly becoming clear, but when we started this was not the case…*" (The Overall Project Manager of the Engineering Consortium, 2010)

The overall manager of the engineering consortium commented on the client demands that occurred throughout the design process. The HVAC engineering project leader commented on the natural dynamic process of changing design by using the example of commercial spaces. He emphasized the update on the initial brief.

"…*Commerce is something that is continuously developing. When it was started, the tenants of those spaces often engage themselves to the rental contract at a very late stage. So they don't engage a rental contract in 2006 for a space they get delivered in 2011. Therefore,* [National Railways, NRD] *is continuously speaking to possible tenants. But before they commit themselves, that takes time. The concept we had for the commercial spaces in 2006 is currently, in 2010, outdated. We have a new concept, new tenants and therefore also a new plan…*" (The Lead HVAC Engineer, Engineering Firm 2)

Nevertheless, this change was only discussed informally and in meetings. There was no official 'capture' of the changed criteria. Hence, there was a request for changing the direction of the project in a revised key document, namely the programme of requirements.

"…*It is an interesting project. Because now that the project is ready, we still have no programme of requirements…*" (Lead HVAC Engineer, Engineering Firm 2)

A similar concern is stated in the following statement: "…The scope was unclear; there was discussion about it now and then…" (Overall Project Manager of the Engineering Consortium, 2010)

He also shifts his perspectives and admits the difficulty of producing and controlling a key document:

"…*You would expect* [the client] *for example to provide a programme of requirements, because that is coming out their organizations* [ProM] *but they don't do anything about that… In the final design stage there* [the client] *had a project brief or programme of requirements… any time I went to the meeting, there were new requirements… Each time there was new, next time new, next time new things, and it was really really difficult…*" (Project Leader of the Structural Engineers, 2009)

"…*You don't want such things to happen in your project…. Changes occurred too much…*" (Overall Project Manager of the Engineering Consortium, 2010)

"…*The preliminary design was made without a good program of requirements. There only was an 'the necessary square meters of areas, parking places, housing, offices, and terminal building'. At the final design phase there were multiple program of requirements and actors were having arguments about the content. Now that the tendering documents are being made, still requirements are elaborated…*" (The Project Leader of the HVAC Engineers, Engineering Firm 2 2010)

The overall project leader of the engineering consortium commented similarly regarding the program of requirements:

"…*There are only two ways to do it right. Arrange that your programme of requirements is crystal clear, or if that is not the case, you will have to do something in the process to assure that the final result will be as you want it to be…*"(Overall Project Manager of the Engineering Consortium, 2010)

Controversially, the client representative had a different view on changes and the program of requirements:

"…*I am sure the design that is made; it is made according to the requirements. It is made within the budget. But during the development of the terminal complex the world has changed…*" (Representative of the client consortium, 2010)

He implicitly states that the changes are in the nature of the design and that no one could have predicted what the market conditions would be. The market change mentioned in his statements highlights the decision behind the second cost-reduction and therefore for the second re-design. Similarly, the overall project manager of the engineering consortium highlighted the challenge of defining the demands beforehand, although he slightly contradicts his above statement:

"…*Well, sometimes it is very difficult to describe your demands. At least as difficult as making a design*…' (Overall Project Manager of the Engineering Consortium, 2010).

Case 2 included two radical client-driven market changes as discussed above. This caused parallel design work with two different design criteria. In Case 2, this radical shift in the design process resulted from an institutional change; privatisation. Before the project started (between 1996 and 1990, there was a long period to define the scope, which changed due to the integration of the scopes as described above. The privatisation cut directly through the existing scope, the set the roles between client organizations and design team members, responsibilities, legal arrangements. This institutional change shifted the direction of design from maintenance-oriented to operation-focused. The change in client structure, the dynamic scope and the design process that attempted to catch these changes created an unstable environment. This environment was further impeded by the long chain of approvals on both the client's side and the involvement of the original authorities. These long chains inhibited the prompt applications of any changes to the design process. In Case 2, a similar issue occurred with respect to the client structure. Further to the government-driven institutional change, one client organization; National Railways, used their financial position to change the scope of the project, as discussed in the section on cost reductions.

"[The threat of National Railways to step out of the project] *means we are not going to make the offices so we have to start the design again. So we just will make a railway station and get angry at each other*…" (Client Representative of the ProM, 2010)

Both examples depict how unprepared the organizations and the design team members were with respect to any type of organizational change. The duration was long as there was no guarantee of building stable relationships except for the contractual agreements upon which organizations based their trust. It is highly possible that the clients had contradicting interests, resulting in an unstable environment. The outcome of this uncertain environment resulted in a fluidity of design criteria that caused a fluid design rather than a dynamic design. Design has a dynamic nature when it is an iterative process that moves back and forth while developing. Yet whenever the design criteria changed, this necessitated a re-design based on the new criteria. Cost reduction, the changing interests of the stakeholders over time and/or developments in client requirements are examples of causal factors. These changes are the consequences of institutional, organizational changes in the project environment as well as difficulties in the design process, for example when the design first starts as an abstract idea that should result in a feasible construction. The first two changes are difficult to foresee, unlike the changes in design elements caused by, for example, technical impossibilities, making complexity factual.

Key project documents should describe the level of a project's complexity such as the original brief (which can be used interchangeably as a Program of Requirements and the scope). In both cases, the brief was used as a 'scapegoat' for the projects. It is naive to believe that the original brief can be completely clear. Often a brief provides indications for the designers regarding design restrictions, or the desired design solution. However, many designers expect to have a static document, which will guide the design process. Yet, this is contradictory to the nature of the project as a unique product. The brief should also acknowledge the fact that the design and the brief will evolve together. In the beginning, the brief is only a statement of requirement, a wish, and a prerequisite. As the conceptual design unfolds, the brief gains an identity upon which the client and the designers agree. Problems occur at the moment when the brief no longer represents the current design. As the design process is phased, the main document that encapsulates the clients' requirements of the design criteria should also be developed throughout the design process.

§ 4.5.2 The Strategies to Overcome Complexity

Up until this point, the complex nature of the projects and the problematic issues that interfered with the project's progress have been discussed for both cases. It is now important to look at the ways that practitioners develop to overcome these project issues. In both cases, one key strategy emerges: projects are divided. Dividing the projects into sub-projects in both cases emerged as a means of overcoming the issues as well as enabling the designers to tackle unique endeavours. The division of work represents a systematic way of tackling one-off and temporary features of the projects, however not the properties themselves. At the stage of task definition, division of work is limited, as it requires more visionary alignment and collective goal settings. Thereafter, task decomposition is appropriate where the vision needs to be realized and divided into disciplines and then sub-divided to become an operational and manageable product and process. The interrelation between the decomposed tasks enables a connection of the tasks and practices in order to allow the organizations involved to achieve their objectives within the main goal agreed upon by all parties. Here, the emphasis is on the difference between a permanent organization's goals and the temporary systems used to enable task achievements. It allows us to connect the variety of contextual influences that different organizations have on the projects. The emphasis on the interrelation of tasks has to refer to the importance of the interactions required to 'connect' the sub-divided tasks, which cannot simply be separated.

The required connection between the divided sub-projects was facilitated by a series of strategies, management tools, and techniques. These strategies referred to the creation of physical places in which designers came together to work both intermittently and continuously. As discussed in the section on temporality, examples of intermittent efforts are meetings, workshops (found in both cases), and continuous efforts (long-term in Case 1) such as co-location and the introduction of new tools (4D models, BIM or 3D models).

In Case 1, co-location was twofold; both teams of clients were co-located and the design team members were co-located. The client's co-location was described as "... *They* [department] *created a joint client team between* [The Underground Body] a*nd the department of transport. And our team had some people from the department of transport, project representatives in it and some people from* [The Underground Body] *in it. And we worked totally together as a single team...*" – a statement by the client representative from the department. The motivation behind this co-location was to ensure that the scope of the work developed in such a way that it was advantageous to the other projects with a close relationship to the other members. For the design team members, co-location was intended to manage design changes in a complex project, which was described as 'the largest one in the engineering company's history' by the Program Manager in 2008. The first step was to create a physical environment in which architecture, HVAC, public health, programming and phasing, commercial, and financial crews, client representatives, and contractor's representatives could all be accommodated.

In Case 2, this interrelation of sub-projects was achieved through design coordination meetings. In particular, these meetings were held with structural engineers, so that each day was organized as a decision-matching series. The day was structured in particular time slots per division; morning, noon, afternoon 1 and afternoon 2. This structure influenced the design crew meetings. The meetings were also structured in order to retain the updated information and to ensure that the work was carried out based on the updated versions of the projects. Tasks were used to subdivide the project into smaller parts – despite the fact that some parts were complex and perceived as being indecomposable. This division enabled management of the complex nature of these projects and the main goals to be achieved (i.e. to fulfil the clients' expectations within the time limit and the set budget, to achieve organizational and/or disciplinary objectives).

The meetings also worked as internal deadlines for the exchange of updated design information. Such deadlines are common practice for dividing complex tasks in a determined way, clarifying what is expected from the parties as deliverables (design objects) at a pre-determined deadline. Deadlines do not only refer to the milestones, they determine the processes and the tasks to be realized within and after these deadlines. Although deadlines may cause a collaborative 'paralysis', due to the tension of trying to meet them, the tasks need to be interrelated and allow the organizations working on their tasks within their disciplinary islands, to meet their deadlines using their own methodologies and work cultures, and collaboration. This cannot be accomplished by a mono-organization or discipline, and it requires a collaborative rhythm.

Yet in both cases, the re-composition of the divided project parts turned out to be problematic. It created a trade-off situation; decomposition was necessary to handle the project, yet the interrelation between the parts caused greater problems. In other words, decomposition creates new problems, and therefore requires new strategies for solving these. In Case 2, technology was used as a method of overcoming the complex design issues. Later in the design process, the high level of change led structural engineers to develop other solutions, with the help of technology. As an example of a new strategy (bottom-up), a draftsman, experienced in both developing and running 3D models, proposed that using a 3D model would be a better solution for a project in which the design changed regularly. By using the model, all the layers of the projects could be visually integrated. Together with the lead engineer, the project was divided into "pieces" and they came up with the model "as if it were four separate buildings." Through the first efforts on the model, a mismatch in the overlaps of different disciplinary layers of the project became visible. A number of errors were discovered that had not been previously recognized. However, the phase was already a final design, and all the drawings were in 2D. The architects were using AutoCAD and the engineers were using Bentley Micro Station. Moreover, the model happened to be very premature and missed many details. It also needed more time than the 2D. The model would provide more exact results, once the elements of design had been modelled (or re-modelled due to the changes/ revisions). At that moment, a conflict occurred: either they had to stop using their model and all their efforts would have been pointless, or they could continue to use the model and gain more experience, but also spend more time on using the model. The use of the model led to several different views:

"It costs lots of time, and then it is just better to do it yourself then the loops of sending and explaining what is actually meant. (Project Architect 1, 2010)

"That is like the game we used to play, the Chinese whisper game. When you say something then tell it to others, and then he tells it to others, at the end you get something different." (Project Architect 2, 2010) "

"It was not like that we are going to communicate in one model and build one model. At a certain point [The Engineering Firm 2] *came just with the model, and we have already made a lot of 2D drawings* (Project Architect 2)*, so a lot of sections (*Project Architect 3), *yeah a lot of sections* (Project Architect 2). *So it was already too late, I assume it was because of clash of the two cultures. ...*[W]*e saw the 3D model and said* (with all laughing), *yeah OK it is a 3D model. It is not offering anything new, no new insights..."* (Group Interview with Project Architects, 2010)

These statements illustrate several issues regarding the model introduced by the structural engineers. Firstly, the late introduction of the model in the design phase led to time constraints with regards to becoming familiar with the 3D model, compared to continuing using the existing method. Secondly, the model was a mono-disciplinary tool mainly designed for use by structural engineers.

"…*If it was at the start of the project when you make the preliminary design, it could be very helpful* and *useful if you set up a 3D model. You work it out to be more and more detailed, it gives you a lot of understanding of the project, but working with it was consuming quite a lot of time* …" (Project Leader of the Structural Engineering Crew, 2010)

The structural engineering project leader claimed that the time required for developing the model is an important indicator. The architects also referred to the timing issue regarding implementation of the 3D model;

"[Introducing the 3D model] *was a bit late, when we finished our drawings. A 3D model is just a way of communicating with the contractor and the client…They* [contractor and client] *need 3D, the client especially; they don't interpret the drawings as we can…*" (Group Interview with Project Architects, 2010)

This quote illustrates how the architects excluded themselves from using the model as they argued they did not need it; the building was already 'in their heads'. These varying views show the frustration and the disdain of the architects towards the model's implementation. On the one hand, their view was acceptable, as the model often hindered the structural engineers from meeting the project deadline. On the other hand, the architects lacked awareness of the potential of these tools, as they perceived the new technology might limit their creativity.

In regard to temporality, the projects lasted for a significant time period in which technology use is likely to change. With a view to using technology as a means of supporting a given strategy, these tools should have initially been introduced in the pilot cases rather than during the largest and most complex project of the organizations participating. Introducing a technology should enable solutions, and not be seen as a source of problems. In Case 2, there was a naive idea behind the implementation of the new 3D model; that it would solve production and communication issues yet the implementation required a higher level of skill and knowledge which would have been better had it been trialled in small-scale projects.

Complexity-driven project problems such as client structure, technical challenges, scope change and institutional change need to be understood in order to be resolved. As for the two concepts of temporality and uniqueness, complexity is often made a scapegoat for the problematic consequences in a project environment. What makes a project complex is often known beforehand; the number of stakeholders and their varying interests, the number of authorities through which design is approved, the program challenges such as conflicting interests, site, structural, aesthetic and engineering challenges, etc.; these are the known facts, determined even before a project starts. Yet, it is often not these facts that become problematical as the project develops. Rather it is these problems that occur when project timing becomes an issue. In other words, the anticipated project progress does not match the actual project progress because of these influential factors that bring a level of uncertainty to the project.

§ 4.6 Conclusion

This chapter presents the empirical data analysis in relation to research question 1. It addresses the nature of LCBPs and the manner in which this creates barriers to deliberate knowledge sharing strategies. In the literature, the unique, temporary, and complex nature of projects have been reported as barriers to strategies that combine investing in social relationships and tools that specifically target inter-organizational interactions and shared-design processes for projects. Our analysis of the data revealed three conclusions, which can be applied to these three concepts..

The first preconception from the literature was that projects are unique and therefore it is not possible to design and implement a general strategy for any project, as projects always have a unique scope, organizational structures, and relationships. The analysis of the case data shows that the two LCBPs had significant commonalities despite their unique nature, and that the actors had the tendency to underestimate the generic nature of the projects. This leads to the first conclusion concerning the nature of LCBPs.

1 Uniqueness is perceived as an integral part of LCBP and may initially even seem desirable. However, uniqueness can present a stumbling block for establishing knowledge sharing strategies. Emphasising the generic elements of projects presents a better basis for knowledge sharing strategies.

The second preconception was that, since projects are temporary, implementing a strategy that stipulates investment into social relationships among actors is unnecessary. However, the data analysis showed that particularly for large complex building projects, 'temporality' was a relative concept. Both cases represented at least a decade worth of work for the actors involved. Throughout this period, both projects developed local practices to facilitate social interaction, but in neither case were these practices designed as essential mechanisms. In both cases actors made efforts to deal with the social and technological sides of knowledge sharing processes, yet these efforts were mainly intuitive, rather than deliberately designed as an inter-organizational strategy. This leads to the second conclusion for LCBPs.

2 Most LCBPs last 10-15 years, and thus merit implementing an investment in knowledge sharing practices. Considering LCBPs as temporary is a mind-set that hinders any strategy that targets inter-organizational knowledge sharing processes.

The third preconception refers to the complex nature of projects. A common perception is that the complexity of large projects makes it impossible to design and implement project-specific strategies that deal with the social complexity of the design team as well as dealing with the functional and technical complexity of the design product. The data analysis of the two cases revealed that complexity is indeed a problem, but that it was further complicated by the instability and unpredictability of design processes. Therefore, any planned approach will fall short of addressing issues that emerge in the design process. We also found that the two cases were very organic and highly influenced by the internal project-specific dynamics (such as client changes, criteria changes) and external factors (recession, market changes). The impact of these external and internal factors indicates a similar issue: there is a constant change of design criteria and a constant mismatch between the criteria and design, while achieving a coherent design encapsulates the divisions of the large and complex solutions. Using two examples of LCBPs, we attempted to identify underlying issues behind complexity such as the unpredictable and instable nature of LCBPs. Additionally, both cases also illustrated that the manner in which actors try to achieve a coherent design made LCBPs even more complex. The high degree of division of labour that is required to manage the complexity of these projects, actually contributed to the complex nature. Because each division in LCBPs became a semi-independent project in itself, the interrelation of these divisions became problematic. Based on the results on the complex nature of LCBPs, the third conclusion is as follows:

3 In LCBPs, complexity as such is not the major problem, but fluidity and interrelations between sub-systems are. This is due to the high degree of division of labour: There is actually no single project. Large, complex projects are commonly decomposed into parts in order to make them manageable. Each part becomes a project within a project and develops its own design criteria. A knowledge sharing strategy needs to take this division of labour into account and provide instruments for supporting coherence among sub-tasks.

5 Empirical Data Analysis II: Current Knowledge Sharing Practices

§ 5.1 Introduction: Analysis approach

This chapter reports the findings regarding research question 2, the current practices of knowledge sharing: co-location in Case 1 and BIM in Case 2. The analysis of the two cases comprises the individual analysis of each case and the cross-case analysis. The individual case analyses are based on the framework presented in Chapter 2. These analyses portray to which degree the co-location office as a people oriented KSS and BIM as a tool-oriented are enacted as KSS. Individual case analysis firstly starts with reviewing the way that the selected strategies, both the co-location office and BIM, are implemented and continues with portraying the emergent strategies that deal with the aspects of KSS. The individual case analysis secondly goes into the details of how people enact the implementations targeting the aspects of the selected KSS (Physical Settings, Tools, Procedures, and Social Practices). After two in-depth individual case analyses, the cross-case analysis illustrates the advantages and disadvantages of the two different approaches and enhances the generalization of the research results. The cross-case analysis is concluded with both elaborations of what forms of different social practices occur in LCBPs and to what extent these practices refer to knowledge sharing practices as a result of these implementations in relation with the knowledge sharing in two LCBPs. In the end of this chapter, the conclusions are provided as representing the current extent of KSS based on the two cases and the current knowledge sharing practices of the actors involved in two projects.

§ 5.2 Analysis of Case 1: Co-location as a people-oriented KSS

This analysis aims to answer the following sub-questions:

1. What were the intended and realized strategies of the long-term physical setting provided by co-location to knowledge sharing practices of actors?

2 How did the rules and procedures associated with co-location affect knowledge sharing practices between actors?
3 What was the role of tools in co-location; were there any specialized tools that supported knowledge sharing processes of actors?
4 What were the effects of the implementations for physical settings, procedures, and tools on forming social practices? To what extent did social practices represent knowledge sharing practices under these effects?

§ 5.2.1 and § 5.2.2 provide answers to these questions. Firstly, co-location is discussed in terms of an intended top-down strategy and in relation to the main question. Secondly, the knowledge sharing environment resulting from co-location and dimensions of this KSS is analysed in terms of the sub-questions.

§ 5.2.1 Intended and Emergent Strategies in Case 1

As reviewed in Chapter 2, co-location is a strategic attempt to create a long-term physical setting in which the main design disciplines can be accommodated throughout the project duration. It aims to increase interactions (Rafii 1995) and ease informal communication (Teasley et al. 2000) in order to overcome major project difficulties (i.e. communication breakdowns, delays, misinterpretations) through physical proximity. As a strategy, co-location involves developing the workspace organization, fluid interactions, information access and collaboration styles (Sharifi et al. 2002). With regards to the KSS promises, co-location promotes collaboration between actors as they share the same physical settings on a long-term basis. We analysed to what extent the realized strategy and the way that co-location was implemented had fulfilled the potential of co-location as a long-term physical setting.

In this LCBP, 'co-location' as an example of people-oriented KSS was implemented. It was an intended top-down strategy initiated by the overall design leader of the engineering firm. This design leader implemented this strategy with an explicit aim of "*bringing people together in a same shared-physical setting.*"

Bringing people together refers to planning the actions to arrange a physical setting in which eleven different design crews from three different organizations were accommodated. These actions included selecting an office location, identifying the types of disciplines and the numbers of people participating in co-location, and designing the spatial arrangements of the co-location office (including both disciplinary and inter-disciplinary design spaces for people). The overall design leader was responsible for these actions, as he became the actor managing the development of the co-location office. His responsibility included periodical revisions of the spatial arrangements including the placement of each crew within the co-located office. Co-location was initiated from the onset of the project after client teams appointed the engineering party responsible for the overall design services. The architectural crew came from another organization. The majority of the staff working on Case 1 worked in co-located office throughout the design process.

The intentions behind co-location included "handling the number of interfaces amongst various disciplines, the need of dealing with dynamic issues of the project as the difficulty of managing design elaboration, smoothing information flow "(Lead Structural Engineer, 2008) and "managing changes in a major project" (Lead HVAC Engineer, 2008). The decision for setting up a co-location office was taken in order to handle the complex nature of project. The following quotes by the design manager and the program manager exemplify the intentions behind co-location and set the relation between co-location office and the complex nature of the project.

"*...This is a very big project. It was one of the biggest ones in the time of* [the engineering firm's] *that time....We needed a co-located design team; the architects, the structural engineers and the mechanic and electrical, public health and communication engineers* [are] *all in the same office...*" (Program Manager, 2008)

"*...Be aware of that we are working in the* [historical] *buildings here and all that kind of things, many, many interfaces. We are all from different parties, and slightly see that. All people they have to be there* [pointing co-located office]..." (Overall Design Manager, 2008).

The quotes above reveal that the scale and complexity of the projects was one of the most important reasons for initiating an inter-organizational strategy like the co-location office. These actors perceived bringing physical proximity to the actors in a co-location office as the only way ("*...they have to be there...*") to deal with the multiple actors and their requirements/design processes. However, from observations made within the co-located office, co-location did not achieve its full potential. There were mismatches between the intentions of managers who aimed to bring people together, and the implementations of managers that resulted in detaching actors from each other within the same working environment. Due to these mismatches, the co-location strategy did not result in more than being a shared-office space for actors. The co-location office contained a broken link between the management level and the technical level. This broken link resulted in 'thicker' inter-disciplinary boundaries between the actors in the co-location office and in two different social practices.

The intentions of 'bringing people together' (Overall design manager of the engineering services, 2008), 'closing physical distance between people' (Lead electrical engineer, 2008), 'getting the message out there in co-location' (Overall design manager of the engineering services, 2008) revealed concerns about the existing disciplinary boundaries between disciplines in Case 1. After analysing the data, two degrees of boundary crossing were observed.

1 Design leaders who interacted regularly, engaged in both ad hoc and pre-scheduled conversations, thereby breaking both their organizational and disciplinary boundaries by ‘walk and talk’.
2 Designers who preserved their disciplinary and organizational boundaries in co-location by continuing their organizational practices (previously gained) had a low-level social interaction with each other.

Below, the quote of the program manager exemplifies the boundary crossing role of the design leaders.

“… *The advantage of the co-location is that they* [referring to the actors representing different disciplines] *are just down there in the office. You can just walk and talk. I talked to all the disciplines. If I picked up a particular problem, I could mention it to the appropriate discipline and say; were you aware of that? And trigger the total process again… So managing the team involved finding out what was happening by trying to get people to talk together…*” (Program Manager of the Engineering Company, 2008)

Although this quote emphasizes information sharing, it does highlight two important issues. Firstly, it highlights the aim of co-location as ‘being in there’. Secondly, it highlights the danger of attitudes; a self-assigned “trigger role.” Since the program manager “walks and talks,” getting information about different design processes and trying to inform the relevant designers (or even add the inputs) individually, this attitude may have influenced the perception of the designers so that they no longer needed to communicate strongly. An example of this is the individual trying to patch the potential missing parts of the design. This demonstrates the ‘double-sided’ profile of attitude: although this attitude was performed with good intentions, it formed an obstacle to creating social interaction between the disciplines.

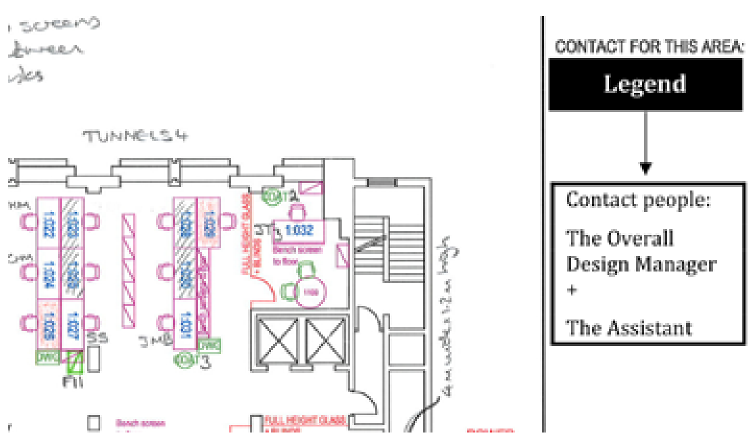


Figure 36
Example of the revision document of the co-location office made by the overall design manager and his assistant

In the end, as an intended top-down strategy, the co-location office failed to achieve the desired knowledge sharing among actors due to the planning and implementation. The actors were divided in their departments; their interactions were only promoted at design leaders' level. Therefore, there was no feedback loop between technical and design leaders' level. Additionally, the designers who used the co-location office did not participate in designing their own shared-office. Figure 36 reveals that the use of the shared office space was determined by the overall manager and his assistant.

The managers who initiated and became responsible for the co-location office did not evaluate the actual use of the shared office and did not communicate their initial motives for setting up the co-location office to the actual operations. In the end, the co-location office turned out to look like any other open-plan office that combines a number of different departments.

The observed social interaction between different crew members was low compared to the intentions of managers. Furthermore, the potential problem of this intended top-down strategy was that it might overlook the emergent approaches that could arise at the technical level. Analysis of the data shows that the actors in the co-location office did not face this problem. An example: an engineer from the tunnelling crew developed software to deal with submission problems of design deliverables of design organizations and to manage these deliverables explicitly between the client and design team organizations. This was an evidence of formalizing the way that boundary objects were to be prepared, sent and retrieved. The overall design managers valued this effort and embedded to the design process. It became an emergent strategy, since this software-use became a part of the shared practice among actors. Even though the overall manager valued this emergent effort, he overlooked two issues in the project; 1) understanding the root of the problem that made the software emerged and incorporating the emergent strategy to co-location and 2) evaluating the reactions of the actors about the actual use of co-location office. Both made the potentials of co-location missed, as the first issue would empower the tool dimension of co-location and the second one would deal with the social practices due to incorporated feedback of actual users of co-location. Below, we report on the way that actors worked in the co-location office.

The co-location office was set up to be a shared physical setting, reflecting the division of labour in the project in a physical setting. Although, sharing the same physical design space had a potential for designers to perform both interactive and participative shared-design practice among the actors working in the co-location office, observations revealed that the level of shared practice that one would expect from designers who worked in this setting for long time was not high. Although the design leader periodically revised the co-location, he did not distinguish the co-location as being more than a long-term office. These revisions did not include the requirements of the participating actors, and were not outcomes of explicit 'trace-back' process of co-location. The trace-back process refers to an evaluation process of a deliberate strategy to see whether intentions had been achieved and that the actors' feedback had been recorded. Since there was no such evaluation, the design manager did not perceive that the co-location was far away from bringing the actors' design processes together. In the fieldwork, observations revealed that the crew members preserved their disciplinary boundaries and that interaction among the crews was limited to the level of design leaders. No distinctive social cohesion was observed among the design team members, as one would assume that these actors would engage in joint-acts such as ad hoc design conversations, casual dialogues, common lunch/coffee habits, etc. During the fieldwork, on a number of occasions, I noticed that the actors from the different organizations knew very little about each other; particularly the designers who were from different organizations. In the fieldwork, on my initiative, I became involved in casual conversations which revealed that the designers had made presumptions about the 'newcomers', unless the newcomers worked in their own disciplinary islands. I was 'presumed' to be *"one of the others."* In the fieldwork, I was referred to as 'another architect' by the actors I engaged in conversation with when talking to the structural engineering crew, or as a 'structural engineer' when talking with the architectural crew, and as 'a new administrative staff member' by the HVAC group. The social experiences in the fieldwork showed that there was a problem of fragmentation within the co-location office, in spite of the long duration of designers working there. I had observed that the majority of the social interactions occurred between designers working in the same disciplinary islands. The reasons for these limited social interactions are discussed below.

Firstly, co-location aimed at 'bringing people together' was implemented by creating functional and organizational divisions within the shared office. Basing the co-location on functional and organizational divisions reinforced the boundaries between the different design crews rather than diminishing them. When planning this, the manager responsible for the co-location office did not include informal interaction spaces in the physical setting. The initiators of co-location did not benefit from the knowledge of the architectural crew appointed to develop the architectural design service. In other words, the domain knowledge of the architectural firm was not used to design the co-location office space. Based on the layouts issued by the design manager, it became evident that the design manager had no intention to stimulate informal and casual interactions among the designers. Although these informal and casual interactions are socially constructed, the implementation of the co-location office had no design feature that specifically encouraged or accommodated these interactions.

The crews implicitly understood that co-location was not intended to stimulate informal interaction, as there was no space where designers could informally engage in ad hoc design conversations or exchange their ideas. During office hours, there were no shared routines such as coffee breaks or lunch rituals. Such shared routines might stimulate informal interactions and casual conversations that could help to ease boundary crossing due to proximity and potentially promote knowledge sharing.

Secondly, the data analysis showed that the initiators overlooked the evolution of the design team and their use of co-location over time. The sketches of the co-located office drawn in the fieldwork and the official revisions did not match. When looking at the drawings depicting the use of co-location with regards to the expansion of the design team using the co-location office, the drawings did not capture any changes made by the design teams themselves. By comparing the actual use of the co-location with the way it was intended, I discovered that the designers made adjustments to their received setting in the co-location office. These changes in the co-location layout were due to the mismatches between the initial layout as determined by the managers, and what individual designers felt they needed in a shared-design space. Thirdly, we observed a low level of interaction between the managers and the designers. The co-location should have provided an opportunity to act as bridge between actors working in management functions and at technical levels. The managers also intended to observe the actual operations of co-location as enacted by the designers on the 'work floor'. The managers had an opportunity to receive feedback from designers on their implementation. Feedback could either be verbal (from designers) or non-verbal (from observations made by managers). The implementer had an option to revise this strategy, if and when the intentions of co-location became difficult to achieve or were constrained by the implementations. Being able to see and hear this feedback would have resulted in a learning loop between the designers and managers working at the co-location. This loop would have revealed the mismatches between the intentions and realizations and it would have enabled the implemented strategy to be updated.

Below, the function of co-location as a KSS is reported based on the dimensions of the Knowledge Diamond framework. Since the focal point of this case was a long-term physical setting, the first dimension explored is the physical setting.

§ 5.2.1.1 Physical Settings

Physical settings comprise both focused-disciplinary and interactive-multi-disciplinary design environments. They are the environments in which actors are present with their domain knowledge, (re) produce, interpret boundary objects (developed as solutions for particular design problems), and socially interact. Actors benefit from the physical proximity and engage in social conversations, observations, and reflections through sharing the same setting. The physical setting of a co-location office can be perceived as an ideal dimension of a knowledge sharing environment (KSE) (see § 2.4.6).

The main dimension of the co-location office was a long-term physical setting in which actors performed their design processes on a long-term basis. Due to the long duration, the co-location office provided an opportunity for the actors to engage in both formal and informal social interactions. We therefore researched the extent to which organizing a long-term physical setting promoted the knowledge sharing of actors. To answer this question it was important to reveal planning actions and implementations in relation to the opportunities of a long-term physical setting. There are five different actions of the implementers found in relation with physical setting component of a KSS. Below, these five actions are elaborated in order to portray the effects of the physical settings to the formation of KSE.

A Disciplinary work environments: Clustering design crews based on their functional and organizational division.

As discussed in § 5.2.1.1, co-location represented a large fragmented physical setting that accommodated unconnected disciplinary islands. In this fragmented setting, the design crews performed their design activity remotely within their disciplinary islands. I observed that the co-location implementation contradicted the intentions of the implementers. The design leader planned this long term setting (as 'bringing people together') by clustering different design crews based on their functional and organizational divisions in the project.

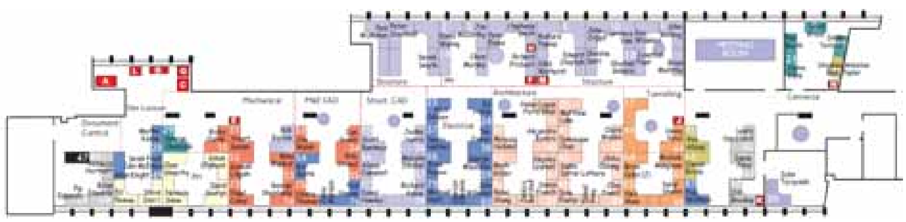


Figure 37
Official layout of the co-location (1 June 2006) showing how the design crews were accommodated. Each colour represents a different design discipline.

The long-term setting of the co-location office shown in Figure 37 reflected the division of work in the project. This would suggest that bringing the design team to the same physical setting was perceived as sufficient for handling the design process together. On the one hand, it was a functional act to cluster the designers based on their work divisions. On the other hand, these divisions shaped focused-design spaces and emphasized their boundaries within the co-location. This division within the co-location pre-determined the way that design team members interacted. This division in islands imposed the division of the execution of disciplinary design activities (activities to tackle the sub-design works performed by clustered knowledge domains). A resulting danger was that it 'thickened' the existing disciplinary boundaries between disciplines. In other words, the fragmented social structure was not new in the co-location, since the actors came from different design organisations or different departments. The problem about the co-location office was that it simply failed to break these existing boundaries down.

The co-located design teams kept their fragmented social structures, which prevented interaction rather than stimulating it. Thus, the division-based implementation of co-location had two sides to it.

One side was that the implementers considered that bringing people to the same physical setting would automatically encourage social interaction between the design teams. The other was that the implementers did not explicitly target social interactions within design crews, but they were interested in bringing the leaders' practices together. The first case is therefore optimistic, whereas the second one reveals indifference towards embracing designers at the technical level. In both cases, planning decisions made regarding the setup of the co-location illustrate an unawareness of the potential constraints and benefits of co-location. These two resulted in two competing motives, which affected the ways in which managers acted and resulted in monopolising cross-disciplinary communication. The managers had failed to integrate the co-location strategy with other intended and emergent (implicit even to the managers) strategies.

Clustering the disciplines based on their knowledge domain implicitly reinforces the segregation of design activities (sub-design performed by clustered knowledge domains) within these disciplinary islands. Regarding interactions within disciplinary islands, the data analysis revealed that the physical proximity of designers within their focused islands was an important factor that promoted social interactions within co-location, but that physical proximity itself did not result in knowledge sharing processes. When designers had a common purpose within this physical proximity and had a common interest (such as a shared problem in relation with same division of work), proximity boosted social interaction. Therefore, disciplinary islands were natural and fruitful environments for designers who had something in common and interaction was natural. These interactions were often ad hoc design conversations, or personal dialogues, and they were performed while designers were engaged in their work. There was no additional action taken in order to 'walk and talk', since the designers were automatically engaged in conversations by simply 'being there' in the disciplinary islands. This 'walk and talk' of managers possibly became an impediment to cross-disciplinary communication by individual designer, as the managers monopolised the 'space' of cross-disciplinary interaction – effectively excluding the individual designers from it.

During the fieldwork, observations revealed that the co-location accommodated inter-disciplinary interactions where designers literally worked face-to-face. When a group of four to five designers were sitting close to each other, even though they were working on different divisions, the group naturally engaged in interactions. These interactions were natural acts, since the designers' main action was to continue working on their design tasks.

B Formal interaction environments: Interactions between lead designers

Another implementation that influenced the social interactions within the co-location was the organisation of formal events such as meetings and workshops. Formal events require a physical space in which pre-planned interactions can occur. These events led actors to formal interactions, which led to opportunities for informal conversations. However, in the co-location office, formal events were strictly managed and limited to the discussion of agenda points in order to use the time efficiently. In the co-location office, only two rooms were allocated for the actors' formal events and their interactions. These spaces accommodated either managerial level interactions (between client, managers and lead designers) or mono-disciplinary technical level interactions (between design leaders and designers within their crews). In the client-design team interactions, only selected lead designers were present.

"*...They* [Client representatives and design leaders from the engineering firm] *seemed to hold meetings like literally on a weekly basis. They had the same time zone for every meeting. On a couple occasions, I have been aware of somebody from* [Private Consortium], *usually* [Matthew, the representative of the Private Consortium] *saying; we really need this information urgently. But I had no idea...*" (Lead architect, 2010)

This quote above shows that the formal meetings were periodic although the architectural crew was not included in these formal events where design issues were discussed with client representatives. Even though the participants potentially engaged in knowledge sharing processes due to their being involved in design related problems, one of the main actors needed an information transfer regarding what had been discussed during these formal events. In other words, organizing formal events and conducting multi-disciplinary meetings was not enough, if special attention was not paid to disseminating decisions, solving problems, and holding discussions within the design team.

"*...The architectural team are almost at the front line of change. Because they set up their overall layouts these are what the clients look at... The difficulty is architects are not totally knowledgeable about civil engineers' and building services' requirements. So when you get a change, it comes true...we have to try and make sure that the other disciplines are consulted about these changes otherwise you end up with an impossible situation...*" (Program Manager, 2010)

The program manager's quote provides a perspective on the parties that participated in client and design team meetings and the problems concerning change and informing those who did not participate. In the quote he admits that architects had a direct connection to the meeting (being in the front line), but that this role did not ensure that the architectural crew participated in client and design team meetings. The two quotes by these two different actors show that formal events (leading to formal interactions) were themselves insufficient for dealing with knowledge sharing problems and that these events did not add extra value as essential actors were excluded from the formal event setting.

The mono-disciplinary meetings, in which the disciplinary discussions were conducted, were held on an ad hoc basis. The design crews used the same spaces allocated to formal events. These spaces provided more privacy compared to the open office format of the co-location office. This reveals a need for disciplinary privacy within the co-location. To the interactions of the managers, individual designers rarely participated. During my field study, I did not find any evidence of multi-disciplinary meetings being held between different crews, when neither the client representatives nor the design leaders were present. The designers who belonged to different disciplines did not take the initiative to discuss their design issues with others. One of the reasons was that they also did not meet in any formal meetings, except one or two designers who attended meetings of the design leaders as 'stand-bys' (see Figure 48 in § 5.2.1.2)

Client representatives formalized the relationship with the design team representatives and interactions as a result of their presence in the co-location. This triggered informal interaction between design leaders, as they participated in the meetings and were able to interact at a level in which the participants of the formal meetings (who had already crossed their boundaries) had engaged in design conversations on an informal basis. The continual relationship between formal interactions and ad hoc conversations within the co-location contributed to building social relationships amongst the participants. This revealed a continuum of interactions of lead designers that started with formally planned interactions with the client team stimulated by the co-location. The formal interactions occurred fortnightly with the client team at the co-location and enabled design leaders to set an interaction rhythm with each other (for the clustered disciplines). As an example, if a design issue needed further elaboration, but it could not be resolved within the duration the duration of a single meeting, the participants at this formal meeting had a chance to continue their discussions within the co-location where they worked.

Working in the same shared office space enabled the lead designers to develop their social relationships, since the leaders crossed functional and cultural boundaries in a formal work environment. Once this continuum between formal and informal interactions had taken place, a shared understanding between actors was achieved. In this case, the possibility of reducing boundaries became greater through repetitive actions, familiarity was achieved between different actors (familiarity with respect to cultural, functional and organizational differences), and design information was interpreted collaboratively within these formal and informal work environments. This was one of the reasons for the improved social infrastructure between design leaders and the (limited) social interaction between the individual designers. These continual interactions of leaders in formal and informal spaces highlighted the lack of formal interactions between designers across their domains. Even though the architectural design crew did not participate in all meetings, the design leader did influence the lead architect's behaviour of crossing disciplinary and organizational boundaries.

"*...I was going every day and checking them* [referring electrical engineering crew] *and saying 'Have we done it yet, have we done it yet?' And you sort of see them discussing this work to progress you just get much more contact and if you see they are not discussing anything, then you need to kick some butts...*" (Lead Architect, 2008)

The lead architect's quote illustrates the 'easiness' of crossing boundaries due to sharing the same working space. As the lead architect participated in formal meetings occasionally, she had enough familiarity and comfort to be able to ask ad hoc questions and to monitor the progress made.

Two interrelated factors that discouraged social interactions between actors from different disciplines were observed. Firstly, designers were not brought together in any formal events (i.e. design meetings, etc.) as the design leaders interacted and pursued their design conversations in their work islands in the co-location. Secondly, the co-location planning did not provide sufficient informal interaction spaces that included areas for both ad hoc design dialogues and casual conversations that could lead participants to engage in design dialogues. This led to the conclusion that the long-term physical setting made formal technical level meetings unnecessary, so there was no need to plan and organize these meetings between designers from different design crews on a regular basis. Since no basis was created for regular and formal interaction among design crews, crossing boundaries across domains remained optional and dependent on the designers' individual choice. The informal interaction spaces then became crucial to bring designers together and socialize to resolve design problems collaboratively in the same office. This leads to another problem of the co-location; the lack of informal interaction spaces.

C Informal interaction space: Accommodating interactions of only lead designers

There were two types of informal environments at the co-location: 1) the spaces that accommodated both ad hoc or planned informal design conversations, and 2) the spaces where designers engaged in casual conversations that potentially led to informal design dialogues. Examples of the first in the co-location were the discussion corners that facilitated prompt actions by lead designers to pursue the further discussions that were initiated in the formal environments. For instance, when the lead architect and structural engineer discussed the design issues in a formal meeting with the client team, they were able to prepare their discussions using these corners. Examples of the second are the coffee-corners and lunchrooms, where casual conversations were encouraged. In the co-location, 'the pantry' was determined as 'a casual space for designers'.

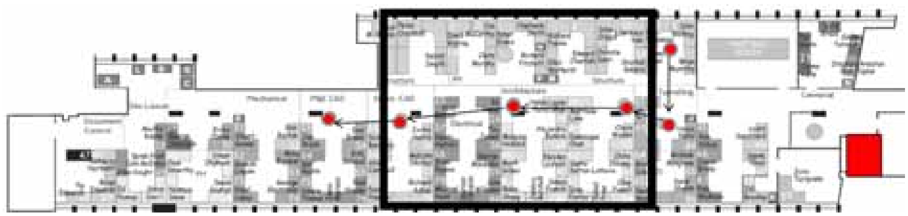


Figure 38
Official layout of co-location based on the date June 2006. In this layout, the red circles represent discussion tables.

These interaction spaces are marked as red circles in Figure 38 and represented 'crossroads' for designers who 'crossed' their boundaries both formally (i.e. design meetings) or informally (i.e. casual conversations). They promoted the development of social relationships. These relationships created a social structure in which exchanged design information could be interpreted and discussed. Although the layout of the co-location shows that each design crew had one-discussion corner for ad hoc design dialogues, the actual use of the discussion corners was different. These corners were theoretically the disciplinary crossroads of the crews, yet they were spatially limited; they could only accommodate up to two people engaging in design dialogues.

With regard to the first type of these two informal environments, the physical setting did not have enough socialization spaces where design crewmembers could engage in social conversations or informal design dialogues. Our analysis of the data showed that limited informal interaction spaces negatively affected the development of social relationships between the different disciplines.

The tables were positioned on the main circulation route (see red circles in Figure 38). The tables were created as small-scale physical settings where ad hoc design discussions could be held. Logistically, being 'on the way' would encourage greater use potential for designers who 'walk and talk'. However, each table was clearly located within the boundaries of the disciplinary islands.

During the fieldwork, it was observed that these informal interaction points were used for design leaders' discussions, while the designers continued working within their disciplinary islands. Spatially, the interactions could only be between two actors who represented their design crews. These actors were often the design leaders, since they dealt with the interrelation of design tasks. For example, if a change occurred in a sub-division of the design, it is quite likely that the change would be reflected in the overall design due to the knowledge (and responsibility) of design leaders which encapsulated several sub-designs. Hence, the spatial limitations of the informal interaction spaces challenged the participation of the designers as far as ad hoc design dialogues were concerned.

One can argue that the designers also indirectly participated into the design leaders' social interactions and that they exchanged design information incidentally. This incidental and indirect participation of designers was because the ad hoc meetings (design dialogues) were held in a shared workspace. Designers were exposed to these design dialogues and discussions occurred in the ad hoc meetings between design leaders, since the leaders' informal interactions were held in the disciplinary islands (see Figure 39). However, while transcribing the interviews, we noted that the participants were barely audible when these tables were in use. Although theoretically the designers could benefit from these nearby and indirect social interactions, this was not the case in the co-location. This was due to the number of the designers surrounding the informal interaction spaces. Figure 39 shows that there were three informal interaction points for 45 designers. A simple calculation shows that each 'discussion corner' would be used by approximately 15 designers in a very limited space (as explained, the tables only accommodated two people).

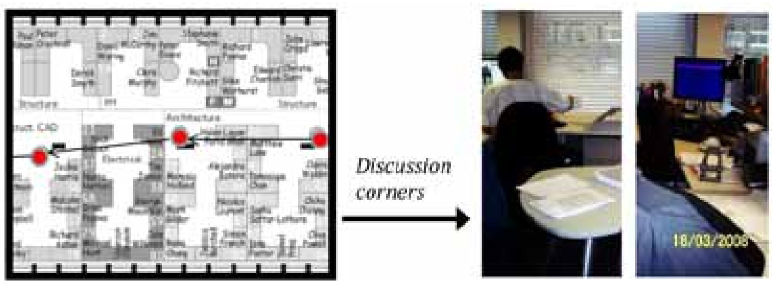


Figure 39

Partial layout of the co-location (left) illustrating the working spaces and informal conversation corners (circles) of the designers close to the circulation path in the middle as well as the colour-coded disciplinary islands. The image (on the left) is the program management disciplinary island taken during the fieldwork in March 2008. It shows the discussion corners where social interaction between design leaders occurred.

Figure 39 shows the three discussion corners for 45 designers working in the four different disciplines (structure, program management, electrical and architecture). It also illustrates the lack of space around the tables. This limitation constrained the involvement of more than two individuals engaging in the ad hoc design discussions held at these corners. When looking at the planning of the disciplinary islands, it becomes difficult to claim that the seating arrangement was an inviting setting for ad hoc discussions. These images suggest that even though designers shared the same physical setting, they were shut out from informal interactions while working on their disciplinary design process. The design leaders benefited from the discussion tables in two ways: as a complementary interaction after formal meetings, and for ad hoc design conversations. In both cases, using discussion corners meant being involved in social interactions within the disciplinary islands.

With regards to the casual spaces, the data shows that the common co-location spaces where designers could socialize without pursuing a work agenda were limited. The importance of a common space is that boundaries are crossed without a reason being necessary as a natural act within a shared multi-disciplinary space. Examples of these spaces are coffee corners, which invite 'water boiling conversations', or dining rooms where engaging social conversations is perceived as normal. The importance of such common spaces is that they do not require deliberate actions to 'invade' disciplinary or cultural territories. However, these spaces run the risk of being dominated by a certain discipline –cultural group. When this risk is avoided, common spaces can serve as neutral ground for designers where taking part has a natural purpose (i.e. waiting for the water to boil, eating lunch, queuing, etc.). Therefore, common places are important since they carry a high potential for easing disciplinary and organizational boundaries without invading the disciplinary islands. Therefore, social relationships could be sown in these settings by inviting casual conversations, which in turn could bring designers to talk about their design task. By participating in common spaces, designers could develop an interactive attitude in those cases where social interactions were not self-evident. In Figure 40, the lack of casual interaction spaces is evident.

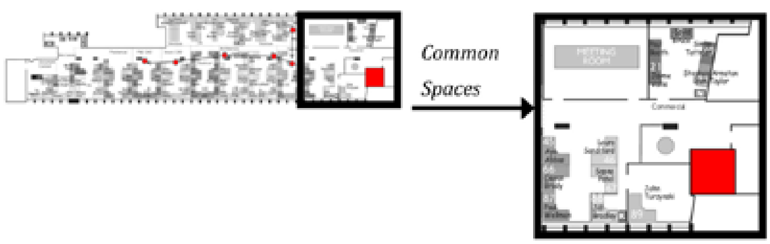


Figure 40

Common spaces (red) allocated in the co-location for 'work-free' socialization areas where casual conversations were held.

The socialization areas marked red in Figure 40 are referred to as 'common spaces'. These common spaces promote casual conversations between the unknown and known individuals who shared same physical settings. In common spaces, crossing boundaries becomes 'ordinary', since conversations do not interfere with anyone's work. However, in Case 1, only one space fitted the characteristics of a socialization space; the pantry (10 square meters). There were no spatial arrangements in the co-location space where designers could meet during breaks and develop a common attitude. The pantry area was not revised to meet the changing needs of the expanding design team. In 2008, only six 'discussion tables' were allocated to the 135 individuals in the co-location. This led to another factor which hindered the development of social cohesion within the co-located design team; the large number of people working in the same physical setting.

D The size of co-located team: bringing 100+ people to accommodate within same physical setting

When we discussed the limited interaction encountered at the co-location, we showed that the number of team members became a limiting factor for the development of social relationships in the design team. Nonaka (1994) discusses that the appropriate size of teams should be between 10 and 30 individuals, as team size increases, direct interaction between the groups tends to decrease.

Based on an appropriate team size and core interaction members, Case 1 is an example of over-crowdedness as the team grew from 89 in 2006 to 151 in 2008, with seven core member design team leaders. This implies two issues.

Firstly, even at the start of the co-location, the team size was not ideal for social interaction and social cohesion, as the initial team size included an overwhelming number of actors in relation to Nonaka's appropriate team size for social interaction. At the start, the team size was already three-times the size the Nonaka's maximum limit of 30. Although the number of the design team in 2006 was not suitable for having easy interaction, the team expanded over time as more designers started to work on the project. However, the team expanded within same physical setting. Over the eleven-year period, the design team grew from 89 to 135 members, and thus more office space was needed for the newcomers. This change represented an increase of 52% of the design team within 2 years. Based on the data, the expected number of co-location members was 151. This represented an expectation of a 20% increase in the design team members in one year. There were two options for managing team growth within the co-location 1) to reduce the size of the individual workspaces, 2) or to reduce the social interaction areas. When comparing the layouts of 2006 and 2008, it can be seen that both of these strategies had been implemented.

This led to the second problem; there was less space for more individuals. Team expansion within same physical setting resulted in a reduction of the existing social interaction areas, as they were required to accommodate the new team members.

The informal interaction environments were already very limited. However, in each update of the physical setting (or seating scheme), which was driven by the expansion of the design team, the only interaction space which could accommodate ad hoc design conversations was eliminated in order to make more room for the growing team. This decision illustrates that the social interaction spaces were not considered as important as accommodating more people, and therefore they could be done without.

These interaction spaces were not treated as an important component of the planning of the co-location physical setting. The periodical updates of the co-location design made to accommodate the newcomers or people or companies who left the project (see Figure

39, Figure 40, and Figure 41) which show that improving social interaction was not a primary concern, although it originally was one of the motivational drivers behind the co-location. The interaction spaces were eliminated from the physical setting as the implementers responded to the increasing size of the team.

In the co-location layout, the architectural design crew were initially planned to be located in the centre of the shared space. The crew would then be at a close distance from the other crews: structure, electrical, program manager, and tunnelling. The official layout dated 24 May 2008 shows that the position of the architectural crew was swapped with that of the structural engineering crew. The reason behind this shift was to allocate the increased numbers of the structural design crew, since at the same time the number of designers in the architectural crew had been reduced to nine. This shift shows that the focus was on the proximity of designers working in the same division of labour. Theoretically, this re-planning had potential, as the re-located crews could be near less familiar crews. However, we observed that the 'rule' of little interaction between each of the disciplines continued within the new settings. Our analysis revealed that the disciplines maintained their boundaries strongly and adjusted their work islands in order to meet the expectations of their own physical setting. This caused self-adjustments of the disciplinary islands over time, and revealed that implementers did not contribute to the physical requirements of the disciplines in the co-location and that they overlooked these self-adjustments.

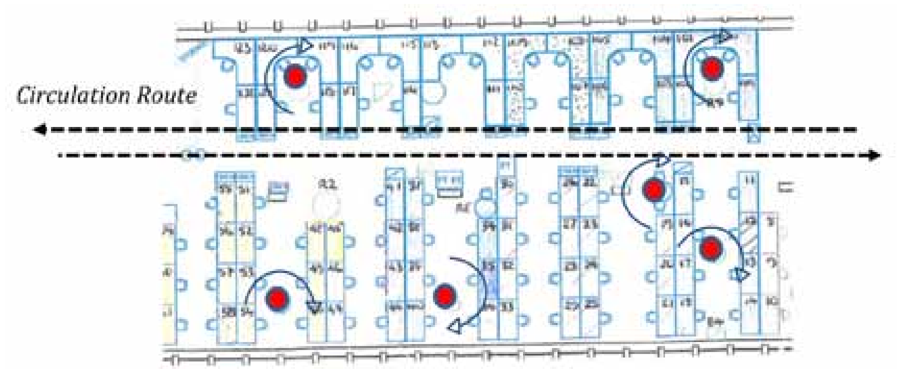


Figure 41
Official update of the co-location layout

Figure 41 shows an example of an official update of the co-location. These updates were made to meet the spatial requirements of the design team, as it increased over time. The changes made either regarded the re-location of the design crews or allocating 'newcomers' to the shared work space. This update was supervised by the overall design leader. In these updates, we can see the reduction of the common spaces (which were already limited) and the informal interaction corners (the use of which was already limited).

Figure 42
Spatial change of the design team over time

In each version (Figure 38, Figure 41 and Figure 42), the increase in team volume emerges as the most challenging factor in the development of social relationships between design crews. In addition to the showing the expansion of the design team, the three versions of the co-location illustrate that the socialisation spaces were eliminated.

E Identically planned disciplinary islands and self-adjustments of disciplinary islands over time

In the fieldwork, I observed how the designers modified the disciplinary islands in order to create focused-work islands that embedded disciplinary needs such as privacy, open space, cubicles, etc. The observation data did not match the official layouts made to plan and revise the way the co-location was to be used. In the official layouts, each discipline was planned identically, except for the commercial crew. The commercial crew were responsible for confidential information such as the budget and cost estimates. As there was a need for these specific commercial issues to be secure, their privacy needs were reflected in the design of their disciplinary islands. In this case, the planning of the commercial crew's physical setting had a direct relation with capturing, controlling, and managing confidential design information (such as cost/budget/ issues). The document management crew (officially responsible for the ensuring that everyone worked on the latest version) was located at the end of the office and had almost no access to other domains. However, other design disciplines such as architecture, engineering had similar layouts regarding the way and space that the designers worked.

All the official co-location layouts show that the design crews were equipped identically. In this identical equipment, the physical setting did expose the hierarchical codes. The different sized (and shaped) tables represent the ranking of the individuals. For example, the larger tables within the disciplinary clusters, (see Figure 40) represent the conversation points where designers could have design discussions with or without their artefacts. The differences in these elements, the number of socialization spaces, and the ways these settings were equipped emphasizes the hierarchical codes imposed on the different equipped individuals (or crews) and the expected use of the spaces.

If the co-location was planned to be an extension of one organization as a project-specific design office, one could argue that it would stimulate the same work attitude in the actors involved. However, the co-location accommodated different design organizations; the architectural crew was detached from its permanent organization in order to function closely with the engineering disciplines within another organizational setting. The different needs of the architectural crew, or different work routines performed by the architectural organization were not reflected in the co-location planning. The implementers of the co-location office presumed that all design crews require identical setting (see Figure 42).

The 'identical setting' approach of the co-location implementers resulted in a 'patching' attitude by the designers. In this way, they attempted to respond to the spatial requirements of the crews. This attitude was observed both in the architectural crew and the engineering crews. It was observed that the design crews modified their working islands in order to create a comfort zone for performing their design activities. These comfort zones comprised altered use of the elements that existed in the physical environment. These elements were things like partition boards, project or empty folders, and a relocation of the discussion corners so that they blocked access to the architectural crew, rather than being a 'door' opening social interactions among crews. In this way, these attitudes over time represented a self-modifying culture in order to pursue existing disciplinary and organizational practices that were challenged by the co-location. This emerges two issues; 1) the implementer of the co-location office did not estimate the different needs of each design discipline's design practice (including what kind of social interactions designers require while they perform their design activities) and therefore did not set-up the co-location's physical setting and 2) designers were not involved or were unable to define their physical environments.

In Figure 43, the area hatched in pink colour illustrates that the architects self-adjusted their disciplinary territory to create more open-office setting that they are familiar with in their permanent organization. The blue-hatched areas represent self-adjustment of engineering crews to create a cubicle setting. In this figure, I recognized that the architectural design crew built their 'fortress' (in pink) in which the crew worked in an 'open' environment. It contains the domains and their division in workspaces and illustrates the self-evolved physical setting over time. The architects modified their layouts as a large open space; they used partitions to surround their territory and provided a semi-private work area. The electrical engineering crew worked in cubicles (see Figure 44). The crew used the discussion tables to keep multi-disciplinary informal interactions outside their fortress. Their focused work islands were closed to the outside world. The structural (light blue) and the electrical (dark blue) engineering crews designed and used their cubicles as they were used to working in their parent organization (observed during fieldwork).

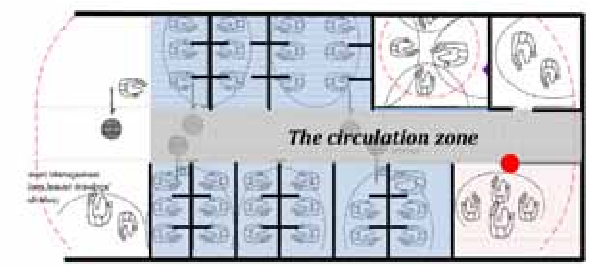


Figure 43
Illustration of the modified co-location drawn induring the fieldwork. (© Bektaş)

As the lead architect claims; "...[At] *the end of the day, it depends on people...It is all about co-location, yes it is a fabulous idea to bring all the people* [together] *...but it is about personal relationships and about being able to bring all the problems to the table...*" While this quote by the lead architect emphasizes the actual situation of the co-location, depending on people and their relationship, it also highlights the need for social and cultural support to make the co-location successful.

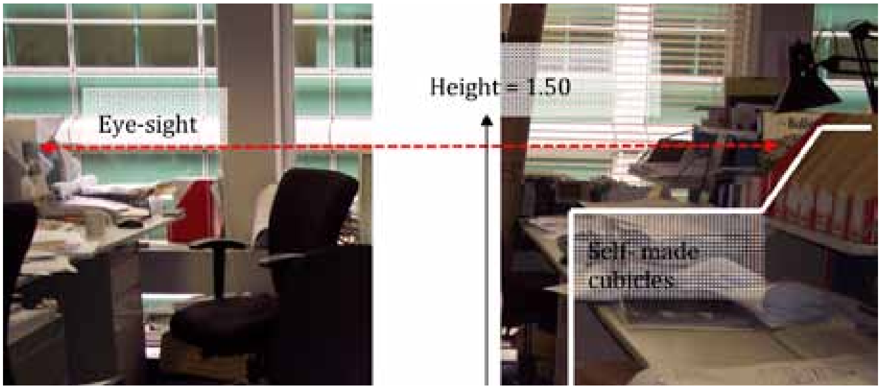


Figure 44
Images capture part of the electrical engineering disciplinary island. The partition elements, which break eye contact between the two disciplinary islands, can be seen (on the right).

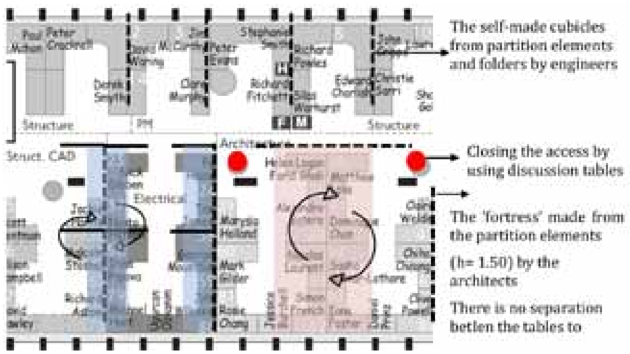


Figure 45
Partial layout of the co-location adapted to represent the self-modified elements.

On the one hand, it was understandable that the design crews self-modified their disciplinary islands in order to create a comfortable design space. On the other hand, these modifications can be seen as feedback from the designers against the implemented co-location. This feedback was non-verbal; the modifications were due to the mismatches between the implementer's idea and implementation and the needs of design crews. For example, by providing a workspace that contains lines of tables (see Figure 45), since the architectural crew contradicted their organizational practice. The area hatched with pink illustrates the open space setting that the architectural co-created in Figure 45 The architectural firm that sent their crew to the co-location required an understanding of the power of physical setting regarding their practices (see § 3.6, Box 1 & 2), as this is understandable from the way that architects perceive the power of spatial arrangements in the built environment. Given their own definition of practice, it is their standard practice to externalize their ideas with the models and model-making spaces, and their informal interaction places are part of this. In their own office, the firm of architects run a café to serve the public and to create a shared routine for dining, promoting informal casual conversations, and design dialogues. These components of their design practice contrasted with the design practice in the co-location office. The firm of architects had designed their parent organization as a work environment that enabled designers to 'pick' and 'add' ideas while using the working space, by allocating their ground floor for meetings, project discussions, and design dialogues as well as creating a model-making studio within an open, boundary-less space. Through the creation of these informal (i.e. lobby), casual (i.e. the café) and formal environments (i.e. model making rooms, open studios), the architects have a greater chance of promoting interactions between designers who can engage in dialogues, and thereby creating a better opportunity for social relationships which could result in knowledge sharing practices. Yet, the co-location did not contain any settings that would enable these actors to become involved in other design practices directly and/or indirectly. This raises the question: why did the firm of architects – so careful about their own work environment – design such a deficient co-location workplace?

§ 5.2.1.2 Procedures

Rules and norms demarcate all the parts of the activity system as both the activity and the larger community in which the activity occurs (Senge 1997). As discussed in Chapter 2, organizations involved in design process bring their own norms, routines, and methodologies. The rules for the design activity of LCBPs are set down in those of the projects and those for design teams. The project rules are the ultimate results to be achieved (defined by the goals of the client), the contractual agreements (as a legal network for responsibilities and relationships), and governing rules (such as communication, interaction and boundary crossing practices of the client organizations which regulate the design team's activities). The design team's rules are more specified towards design activity and are influenced by the project rules. The rules are the effects of the contractual relationships between design organizations (which form the exchange of design information/design objects and responsibilities of the organizations), organizational objectives, methodologies, and routines for performing design activities and the divisions of the work or the large design object. Therefore, in design teams, each organization has its own rule for conveying the design activity.

In KSS, rules are set up to regulate the design team's activities in relation to the project rules, and to develop a shared- culture that enables clarifying design information, easing interpretation and application of the exchanged information by regulating both formal and informal interactions. Related to the KSS dimensions, rules regulate physical settings in which formal and informal interactions occur and design information is interpreted. They regulate the use of tools that facilitate exchange (and storage) of design information and interactions (distant/within physical settings). In this section, we attempt to provide an answer to the question of which rules and procedures were in place at the co-location that regulated knowledge-sharing processes.

The answers are provided by bringing together the 4 dimensions of the Knowledge Diamond. Below, rules for physical settings, social practices (encompassing both for formal and informal interactions of people), and tools are elaborated.

A Rules for physical settings

The creation of this long-term physical setting was the primary component of the co-location. Therefore, the rules that regulated (either implicitly or explicitly) long-term physical setting became important. In our analysis of the co-located office rules, we investigated how the rules and routines influenced the way that the co-location was enacted and the intentions and realizations behind the main strategy were orchestrated.

The analysis of the data showed no evidence of explicit rules that regulated the physical settings as a shared physical setting. No explicit attention was paid to the planning of the focused and interactive work environments in relation to promoting the sub-mechanisms of knowledge sharing. In other words, the actors responsible for the way that the co-location strategy was achieved did not establish a link between the mechanisms of knowledge sharing and the physical components of co-location, which carried a high potential to trigger, accommodate and boost these mechanisms (see § 2.4.6). In the fieldwork, we observed the routines that actors followed. These implicit routines were imposed by the physical scheme of the co-location as being territories for focus environments, with little attention being paid to socialization areas, as discussed in the physical settings dimension. These routines resulted in interaction codes for actors and influenced shaping social relationships within the co-location. Interaction codes occurred in the use of both focused-work and informal spaces as the schematic planning of the physical settings imposed the way that actors behaved in the co-location office. The implicit routines and interactions followed by the actors in the co-location were also due to the different mind-sets of actors, depending on their discipline and organization.

B Rules for social interactions and exchanging design information

Regarding the rules for formalizing interactions, no formal interaction scheme was found between the co-located team and the sub-disciplines that were not co-located. The interaction between the disciplines that were not continually present in the co-location and the ones working in the co-location office was also ad hoc. These sub-disciplines (as the co-location accommodated the main disciplines on a continuous basis) were asked to contribute on a 'when they were needed' basis. This ad hoc interaction code was also a result of the physical distance between the sub-disciplines and the co-located design team. In this case, design crews benefited from proximity, and this physical proximity resulted in ad hoc interaction rules between the co-located and non-co-located design crews.

Figure 46 shows the location of the engineering firm's offices in relation to the co-location. The rectangle marks the co-located design team. The areas marked by arrows illustrate the locations of the sub-disciplines. All these offices were within walking distance of each other. This location setup between the co-located design team and the other permanent engineering offices was a deliberate action to increase interactions between the sub and the main design services.

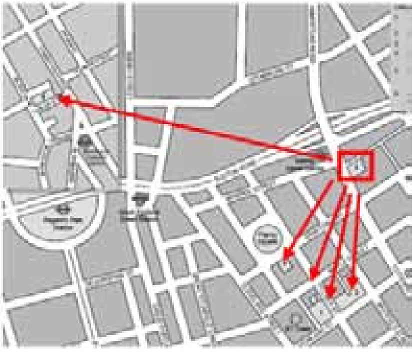


Figure 46
Location of the engineering offices in relation to the co-location

Choosing the location of the physical setting of co-location was a strategic act to enhance interactions between the disciplines. This mind-set behind the importance of being at a 'close distance' was the main idea of co-location. Yet sub-disciplines were less directly involved when compared to the main disciplines, as there was no need for a continual dialogue between the two services. Below, the lead architect comments on these informal codes of interaction:

"*....Obviously we don't meet every week or report every night...You want a specialist on street walls, they work on* [the engineering firm]*'s office, if you need a specialist* [the engineering firm] *has that.*" (Lead Architect, 2008)

In relation to the meetings held for achieving interaction and getting design information from the disciplines not present in the co-location, the following quote demonstrates how the engineering firm's disciplines interacted:

"*...Those people* [referring the disciplines not co-located] *only were called in when they are required in the project...We can then call anybody else when needed...*" (Program Manager, 2008)

Both quotes demonstrate the ad hoc nature of the formal interactions by referring to the non-co-located disciplines. The physical proximity of these disciplines was an advantage, even though the disciplines were not part of the co-location.

C Rules for formal interactions between design and client teams

In the data analysis, strictly formalized interactions between the design team and the client were found. There was a formal interaction code between the design and the client teams. This included the format of the interaction, setting the agenda (design issues as early-cost warnings, design changes, time/potential delays, or problematic interfaces). The rule for the formal interactions was that the crews prepared a PowerPoint presentation, which included design representations (Figure 47). Therefore, formal meetings required more preparation beyond setting the agendas and printing out the necessary artefacts or preparing the sketches.

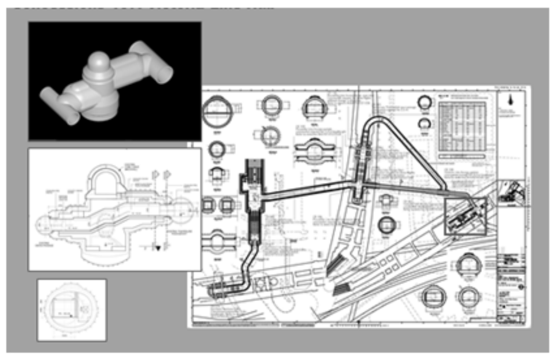


Figure 47
Examples from PowerPoint presentations used to structure client and design team interactions in formal and regular events

This formal structure was due to the interaction 'regime' of the client team to the design team. This regime was to create a routine of social interactions by organizing regular meetings. These meetings were held once every four weeks to ensure that lead designers and the client representatives were in the same physical location. The plan was to keep track of the design process by evaluating the current design object based on the criteria set by the client team. The format of the meetings was clear; each meeting had a title that set the general aim for discussions and file references needed to discuss, the location, the purpose and the list of attendees were included.

The snapshot in Table 6 reveals rules for interaction of individuals at two levels. Firstly, lead designers are revealed as being the main participants. Secondly, technical level designers were seen as 'stand-by' actors. The first level individuals are those who conduct the discussions and the second level individuals are 'on-hold', which means that they would participate when detailed knowledge was required. The snapshot clearly shows the lesser role of technical level designers.

Job title	[Project Name]	Job number	Date
Meeting name & number	Architectural fit-out	File reference	30 January 2004
Location	[the location of co-location]		13:30
Purpose of meeting	Review proposed fit-out design		
Attendance	Five client representatives of the Private consortium	Lead Architect Assistant Lead Architect Two Lead Engineers On 'stand-by': Architect Four engineers representing their disciplines	
Circulation	Those attending		

Table 6

The front page of the meeting agenda of a formal and regular design meeting between the client and design teams

In addition to regular design meetings, design workshops between client and design team management were held annually in order to inform the client about the design process on a regular basis. The meetings also were used to get the feedbacks of the client towards the design object.

"…*We had fix dates from the clients… Initially the client required meetings every four weeks…* " (Program Manager, 2010)

The program manager's quote refers to the pre-planned interactions by mentioning the 'fix dates' of the meetings with the client. The quote also reveals an insight that formal interactions between client and design team were not appreciated when the design team processed the client's design criteria. This shows the dilemma between pre-planned interactions structuring the design process of actors, and pre-planned events that interrupt the design process of actors, once the actors 'know' what they are doing.

Although there was a set routine from the client regarding formal interactions, this routine did contain the actors' participation. As an example, the architectural crew was not always included and this resulted in the architectural design not always being up-to-date, since design information had been altered and this had not been passed on to the architectural crew.

"…[W]*e were kept side out off and since it I don't really mind, cause we had so much else going on and it is kind of* [the private consortium]*'s problem to manage…*" (Lead Architect, 2008)

The lead architect's quote demonstrates that not all design crews participated in the meetings or workshops regularly, although there was a strict planning for the client meetings. The frequency was pre-determined (once in four weeks), yet the attending parties were defined on an ad hoc basis. The outcome of these meetings occasionally were reports prepared by the design team representatives, however these were not sufficient to inform the design team actors, particularly those who did not attend. Therefore, the formal interactions and their outcomes challenged the coherence of the design product, as the parties were not always up-to-date. In other words, the outputs resulting from the design discussions in formal social interactions were not regularly captured. This resulted in a synchronization problem between design team members and the client team members, since both parties retrieved these discussions based on their personal memories. Thus, there was continuity in terms of conducting the interactions, yet there was no continuity in the output and capturing style.

"*…The client has asked us to do things, because the architect had to do a lot of changes and because client has changed their minds, the instructions were given to change the drawings. But the instructions were never given that the building services to change their drawings…. A lot about they were instructing us to do certain things that might be affected by what the architect is doing, so if we are to do it now, we probable have to redo it again, because the architect is changing the drawings …*" (Lead Electrical Engineer, 2008)

This quote by the lead engineer gives an example of an information exchange that excludes the architectural party that was already applying the design criteria changed by the client. The discrepancies refer to mismatches in the exchanged design information. When the lead electrical engineer mentions that the challenge that the 'instructions' are not passed on to all the relevant parties, the frequency of these interactions were raised as being a problematic issue by the leads of the main crews. These were namely the electrical engineering, program management and the architecture design crews. Some examples:

"*…Really this week, the first week I was actually sitting there and looking in my schedule; no meetings that I had to attend for these other two jobs. First time ever, because my week was full of meetings…*" (Lead Electrical Engineer, 2008)

"*…Initially the client required meetings every four weeks with the client. So in practice when the meetings take place actually was a waste of time…*" (The Program Manager, 2008)

The issues mentioned here is not whether the frequency was too high so that the architectural and program management crews only had a limited focus on the design work within their crews. The issue is that the exchanges of the outcomes of these formal meetings and design discussions were not regulated. The high frequency was, however, raised as an issue by representatives of the crews. Not being in the loop of the design information discussed periodically in these meetings resulted in interface problems, and outdated design. The lead architect's quote shows that when an actor was not included in the formal meetings, there were problems about interpreting the design information exchanged in these meetings. The quote also shows the 'forgetting' nature of the client. "...I think that [referring keeping minutes of the meetings] was quite important...At the end of the day even before you get there, you got to have something written down because people are forgetting and it is seen that the memories are not good enough..." (Lead Architect, 2008) This provides evidence for the unregulated outcomes of the design meetings in capturing and exchanging senses.

Besides the definition of the interactions during the regular meetings, the rules targeted the exchange of design objects (needed to overlap with the theme, purpose and aligned with the referenced files), format of the design precedents, and the frequency of the occurrence. This plan included procedures for official deliverables, and identified formal social interactions between client, managerial and technical levels. The format for the formalized social interactions between design team and the client team representatives were to control and manage the design submissions defined in the project schedule. The deliverables are a submission scheme developed to support the planning of the milestones agreed between parties.

This schematic rule described above attempts to clarify the format of the design deliverables submitted by the design team organizations, the organization (from the design team), and recipients (from the client team) responsible for the submissions. The procedure clarifies the process of both submission and review by the client team. The scheme contains a time frame from the submission to the end of the review process including proposing options if problems in the submissions occur (such as the submissions do not meet the criteria). This was an explicit rule for the formal exchange of final artefacts at any particular stage of the design between the client team and the design team.

D Rules for tools

In the co-location strategy, the procedures for tools only referred to a shared-software system for all the disciplines on the project. In relation to the CAD programs, which were to produce the artefacts, the client requested that a specific system be used in order to avoid the version and translation problems between different software: Bentley Micro station. In other words, sharing the same software was a precaution taken by the client team in order to control the version problems and minimize the loss of design information between the parties due to technological challenges. A loss of design information often occurs when different disciplines use different software, and therefore in situations where there is no inter-operability (Chapter 2).

"… [T]*he way we managed the layouts is that all the people working on same computerized system in that case we specified MicroStation. And AutoCAD is quiet often popular in the industry but* [The Underground Body] *specifies that it should be MicroStation. That is their standard. So everybody is working on MicroStation…*" (The Program Manager, 2008)

It was formally agreed that the designers work on the same versions. In that sense, the design team members needed to be in contact with the CAD management crew. This was called making sure of the "fixities." "… *Those* [referring the disciplines] *tend to start in parallel, mechanical, electrical and public health and … through that period initial period all can do is to provide advice but they reach a point in design where they have to have fixities…*" (The Program Manager, 2008). The CAD management crew was appointed by the engineering company to synchronize the various versions and to convert the necessary files so as to ease the interoperability problems amongst various disciplines. They were in charge of "fixating the design version."

The CAD management group was appointed to make sure that every design crew worked on the same version. The architects then worked on a layout up to the defined point. The layouts would then be frozen and passed on to the Mechanical, Electrical and Plumbing services (MEP) team. This with the intention that the MEP team were aware of any changes to that specific layout.

"…*You always get problems when changes occurred when MEP team modified or MEP team make a change and don't notify the architects. So you always get friction on the interface….*" (The Program Manager, 2008)

In addition to the software rules set by the client regarding the existence of and responsibility for the CAD management, an unwritten rule was the exchange of disciplinary artefacts. The rule was that for e-mail communications, whenever a designer crossed a functional boundary, the relevant designers and the leads working on the subject of the division needed to be included. Yet this rule was based on personal knowledge held by the designers and their division of work. In a design team consisting of over 100 individuals, basing rules on personal knowledge is likely going to lead to misunderstandings. This rule was also shared in the emergent software as mentioned in the discussion on tools. The rule for using this software was to include any contact person whenever a submission or change to the system was made. This program was used to store the official artefacts. Neither a written procedure nor an illustration for the use of this program existed. However, the interviewees' statements demonstrated that an unwritten rule did exist for exchanging design objects and design information by the use of tools. This rule was to add the disciplinary contacts (such as lead designers and designers for whom the design information might be influential in their division of work).

The crucial point was to ensure that all disciplines worked on the same version and were informed about upcoming actions or past-experiences. In the analysis of these emails, I found that e-mails were digital dialogues and included lessons learnt and mistakes that should not be repeated. Below is an example:

From: [Nick C. –Electrical Engineer]
Sent: [Date]
To: [Kent V. Mechanical Engineer, Ela B. Architect, Seth D. Electrical Engineer, Umar Structural Engineer, Jim G. Lead Electrical Engineer, Mark T. Lead Structural Engineer, Derek H. Program Manager]

Subject: FW:

[body text including the actors who received this e-mail should respond the issues stated above]

Structures/Architecture/Fire/Electrical/Mechanical [beneath these headings actions and issues were listed]

...A lesson learnt from [the division of the project] is that more attention should be paid to structural and services co-ordination...

Figure 48
E-mail showing digital interaction between designers

Another rule for tools was about regulating intra-organizational knowledge sharing. As described in § 3.6.3, the engineering firm who provided the overall design services except the architectural design introduced a knowledge management system to codify and store the knowledge. The Knowledge Management System (KMS) was not a design tool, but an interactive system that supported organizational practice in order to leverage knowledge sharing between communities. Yet these communities remained within their own organizations. Although this system does not match the context of KSS as it targets capturing, storing, and retrieving organizational knowledge, the rules behind this system are a good example of KSS. The engineering firm had a formal agreement with its employees in terms of promoting the use of this KMS. Employees had a special time allocation in their work schedule. The way that employees contributed to and used this KMS was defined periodically by the department that dealt with intra-organizational knowledge sharing problems. This system allowed employees to combine information gathering internally from the KMS and externally from trusted web pages (See Figure 49). In this way, employees could search, access and/or compile information packages on specific subjects.

These information packages were ready to be interpreted by the employees, therefore the system attempted to stimulate knowledge sharing processes in the organization by using their own sources (internal) and external information 'outside' of the company. This stimulated remote knowledge sharing processes, since the package of information to be interpreted was accessible via their computer. Although this KMS attempted to promote employees' knowledge sharing processes, based on my fieldwork observation, the use of this system was still perceived as a task that 'had to be completed each month' (due to the hours allocation) and not one that was naturally embedded in the design process regarding issues in the on-going project.

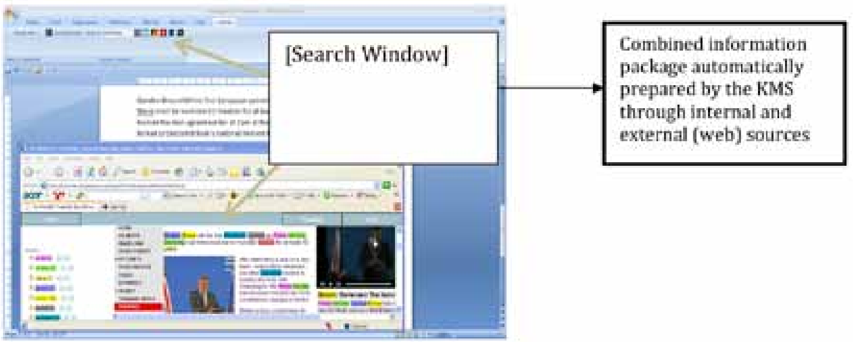


Figure 49
Office procedures regarding the use of KMS and problem-solving (red arrow shows external sources such as web pages and black arrow shows internal sources contained in the KMS)

§ 5.2.1.3 Tools

We investigated tools that facilitated the design process and/or interactions of actors. Although co-location as a strategy primarily focused on the physical setting dimension, by investigating tools we were able to portray the use of tools of the design practices sharing the same physical settings. This investigation of the use of tools helped us to answer the third sub-question regarding the role of tools in the co-location and which (specialized) tools were available to support the knowledge sharing processes of actors.

As discussed earlier, two groups of tools were found: interactive and integrative. Interactive refers to those tools supporting interaction by providing virtual design spaces for collaborative design practice. These tools also include design representation functions. Integrative tools are those used for capturing design information, design decisions/changes etc. to be retrieved for later use. Examples of these are repositories and knowledge management systems.

Regarding the interactive tools, Case 1 represented an ideal first step for tool-focused strategies as the design organizations involved had agreed to use the same software package. The architectural bureau and the engineering firm used this software from the outset of the project. This established an interoperable system among different crews and organizations, which was at the request of the client team in order to avoid data conversion problems. Besides, using the same software for design deliverables was less time consuming when exchanging design deliverables. Although it did not automatically result in a shared virtual space, using the same software represented an initial agreement for inter-organizational interaction. Beside this shared-software, there was no evidence of a digital platform where designers could collaboratively design using the same platform, or interact with each other. The design crews worked within focused work islands as if they were working in their organizational settings. The crew members interacted mainly using e-mail in their focused environments and benefited with the help of electronic interactions, even though they were working in the same setting. Using digital interaction technologies enabled actors to capture and pinpoint official remarks, particularly for inter-organizational design issues. In this way, the actors were able to retrieve the decisions sent via e-mails (see Figure 48).

It could be argued that the opportunity for mediated interaction influenced the limited interaction between the crews. However, actors intuitively built their repositories and captured the design history when there was a need to question a decision taken in the past. The interactions and content of discussions were official and explicit, together with the relevant boundary objects attached to these emails. Actors within the co-location used distant interaction technologies to tackle 'information losses' or to inform the relevant parties (by including the contact designers or using cc functions to inform the design parties in a possible design discussions). The problem in these personal repositories were that the captured emails, discussions and subject design deliverables were fragmented and based on the awareness level of the organizations with respect to the importance of the repositories.

In addition to the design and distant interaction tools, our analysis revealed that each organization used different tools and techniques that the overall design team could have benefited from. For example, the project management company (supporting the client team) had an advanced information integration system (a 4D model) which integrated inter-disciplinary information and was developed as a Building Information Model (BIM). However, their tools were only used as digital models that visualized the project in 3D. The 4D model simulated a real-time construction (See Figure 50). Client representatives ended up with unsynchronized 4D models of the project representing ' actual' time-based construction of the project. The tools did not benefit from any of the design team organization in handling complex interfaces, nor did they help to resolve critical design problems, as BIM and 4D models are designed to do. Additionally, these tools were not updated with the current design information. Therefore, they were used as 'toys' by the client team actors.

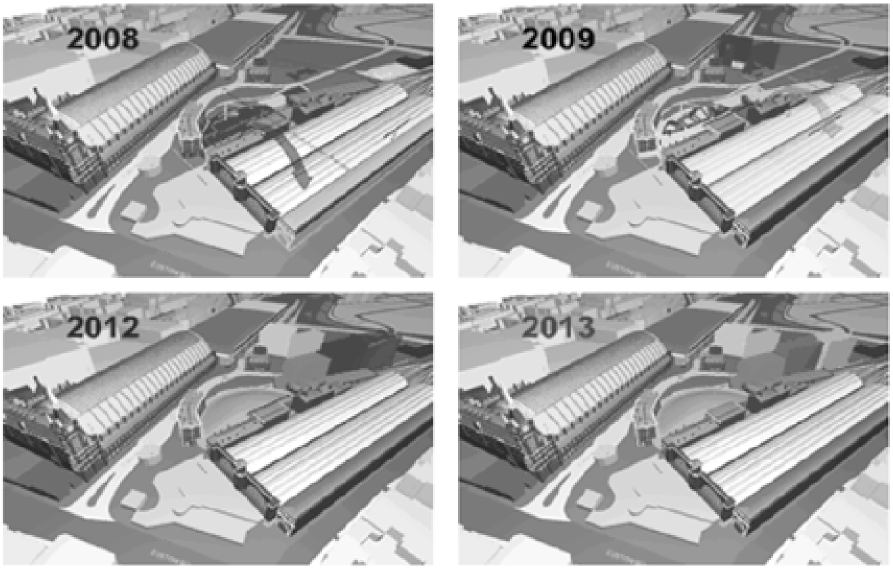


Figure 50
Output of the 4D model used by the project management company (Source: http://www.architectural3d.co.uk/2006/projects_London_KX.htm)

Figure 50 shows the real time construction through the images taken from the 3D model for the years 2008, 2009, 2012, and 2013. These tools provided an overall visualization of the actual form of the design. In addition, these tools integrated project scheduling that could visualize the phases built over time. However, the evident use of these tools during the design progress was not observed.

With regards to integrative tools, our data analysis showed that the intra-organizational knowledge management system that had been designed by the knowledge management department of the engineering company was used solely for organizational knowledge sharing. This system comprised five categories. The first category is 'People' and provided access to people within the firm, which had offices in different continents. The employees had to fill their personal webpage comprising their expert areas, with data on how they solved any challenges occurring in a project's progress. The second category is 'Projects'. Users could search current or terminated projects and their documented data. The third category recorded 'Insights' and this was considered to be the most valuable part of the system. The insights stored were the reflections and reports made by the users. Examples of insights are, 1) statements on how to overcome challenges in a project, 2) how to deal with a specific type of client, etc. Employees were allocated time for this in their work schedule. The allocated time enabled and stimulated personnel to produce more insight into the organization. The fourth category is 'Networks' and it gives access to worldwide project offices. The final category, 'Essentials contained essential data such as common interaction procedures, regulations for specific calculations or structures'. The users did not add their insights and modify the core data. Figure 51 depict a screen-capture from this system.

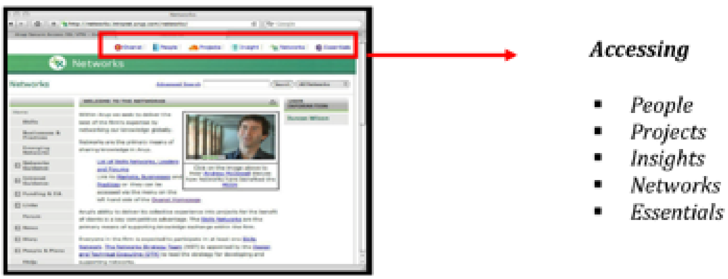


Figure 51
Screen-shot of the knowledge management system

§ 5.2.1.4 A Tool-oriented Emergent Strategy

With regards to the tool-support in the design process, Case 1 included a local practice developed by one of the engineering design crews. It was a self-developed software program designed and initiated by an engineer working in a 'tunnelling' discipline. It was initiated through a constraining issue; making the 'reference design' accessible. The reference design referred to the official submissions of the design deliverables. Due to several version problems that both design team organizations and client teams encountered, a design team member developed software to create a project repository. This repository did not capture design history or changes in the scope/design criteria. However, it was used to pool the official design deliverables and milestones submitted by the design organizations to the client. In other words, the tool was an emergent approach initiated by the needs of the design team, and was used to tackle the problem of 'working on the same reference design' in their local practices.

This tool allowed design leaders to be informed whenever new input had been added. This enabled the contact designers and the lead designers to be aware of the submissions or any official boundary crossing moments. The relation of this local practice to KSS is the intention to build repositories of project deliverables. As discussed in Chapter 2, this is the first approach for managing knowledge (tool-oriented) focused on tools for tackling the management and storage of the disciplinary artefacts. In the context of KSS, a repository only refers to a support mechanism that becomes an 'integrative tool' for design team members when storing disciplinary artefacts, official submissions, and decisions. Such repositories are often mistakenly referred to as knowledge management strategies. They can only take a single step towards supporting the knowledge sharing process among actors, when the systems provide sufficient information for interpreting the knowledge embedded in the process that the stored information is produced.

Case 1 demonstrates an important issue concerning co-location: capturing design information and building a project history (containing the official design deliverables) can be problematic due to the informal nature of co-location in relation to knowledge sharing. In this emergent practice, the tool targeted current problems as well as design representations such as design history, the design decisions that changed over the course of time and the changes that took place in individuals throughout the process. These tools supported the design process by providing a design history to the designers working in their focused work environments.

§ 5.2.2 Conclusions

The aim of investigating co-location as a KSS was to provide a different perspective for looking at current practices in LCBPs. In Case 1, we investigated co-location as a KSS by exploring the efforts spent on each dimension of the Knowledge Diamond framework. Although co-location was implemented as a long-term physical setting, it did not solely represent this. There were intuitive efforts of the actors in realizing the co-location. Co-location represented an important strategic action, even though the actors who initiated and managed the co-location did not foresee this. The intention behind co-location implementations had a knowledge-driven background. The investigation of co-location as a KSS reveals that the full potential of co-location as a KSS was not achieved. Beyond being a strategic attempt, co-location was not even perceived as a special formula, which was necessary in order to deal with the complex nature of a LCBP. Co-location was mostly regarded as a common office floor by both the initiators of the co-location and the designers who worked there. This 'non-special' attitude of the actors towards the co-location limited the achievement of the potential inherent in the nature of co-location (i.e. physical proximity, informal and casual conversations).

Data analysis revealed that the potential of co-location was not used to its greatest potential, as it could have been used as a KSS. Co-location mainly represented a tangible physical boundary for a design team without including deliberate actions making them aware of what could happen within this boundary regarding intentions and actions. 'Bringing actors together' was a principal intention of co-location; yet, implementations did not target anything else, besides the goal of literally bringing people together. Actions throughout the time that the co-location was implemented were mainly targeted at revising the physical setting to cope with the expanding design team, by re-locating design crews. These actions did not explicitly target the way that the long-term setting would be planned; how disciplinary work islands (focused-work environments) and social interaction spaces (collaborative environments both informal and formal interactions) would be organized. These actions remained outside the co-location focus. Therefore, the intention of the co-location as a long-term setting did not fully correlate with the way that the co-location was perceived by the overall design team.

§ 5.3 Analysis of Case 2: BIM as a bottom-up strategy

This section relays the findings of the second case study. BIM was implemented in this LCBP as an example of tool-oriented approach. BIM is a strategic attempt to create a shared design tool in which design disciplines simultaneously work at a distance throughout the project duration. We report the findings of the Case 2 target in terms of the four dimensions of the KSS framework (Physical Settings, Tools, Procedures, and Social Practices) within the analytical framework introduced in § 2.5.

BIM promises that actors can access more accurate design information across different disciplines or different divisions, and it eliminates the need for knowledge sharing through socialization. BIM uses 3D models to help in the design and construction of the project as a way to increase the understanding of the project (Glick et al. 2009). In BIM technology, there are certain requirements in creating a digital platform where participants can add, edit, and control their design input and access other participants' information. Designers place themselves in this digital platform and become visible to each other, work simultaneously, and operate design information together to achieve the multi-disciplinary design object. In this platform, BIM represents a design tool that enables designers to work remotely from their disciplinary islands and to collaborate with accurate design information through the visualized design outputs of other design crews. BIM seeks to facilitate the exchange of information between all actors with the goal of reducing costs, error, and redundancy (Bell, 2004). In order to work synchronously, BIM requires all participants to use the same software or to have compatible programs. In doing so, designers may set interoperable systems in which they 'manufacture' their design inputs and agree upon a level of inputs provided to each other (i.e. the level of details such as properties of the design elements etc.). Glick et al. (2009) note that BIM implementations are not always completely achieved. Spin-off uses of BIM that we are not concerned with include both 4D modelling which adds scheduling to the model, 5D modelling which adds scheduling and costs to the model and conflict detection and planning by sub-contractors. Thus, BIM implementations and realizations vary. In making the analysis of Case 2, we report on the way BIM was achieved.

To sum up, the main question we attempt to answer is to what extent BIM as a tool-oriented approach represents a KSS.

1. What were the intended and realized effects of the tool-facilitated implementation by BIM to knowledge sharing practices of actors?
2. How did the rules and procedures associated with BIM affect knowledge sharing practices between actors?
3. What was the role of physical settings in BIM supported design environment; were there any organized settings that supported the knowledge sharing processes of actors?
4. What were the effects of the implementations for physical settings, procedures and tools on forming social practices? To what extent did social practices represent knowledge sharing practices under these effects?

§ 5.3.1 Intended and Emergent Strategies

The major focus of Case 2 was the use of technology to support the design process and to integrate the disciplinary information by using a design tool. When selecting the case, the managers of the engineering firms indicated that this tool was actually not a complete BIM implementation but a 3D model. This 3D model was initiated by a draughtsman and used by only one discipline as a shared-design tool; the structural engineering crew. The 3D model was not shared by other actors and therefore it is evidently not a complete BIM implementation; it was a spin-off (see Glick et al. (2009))This resulted in a fundamental finding that there was no clear understanding in the current design practice regarding technological concepts such as the difference between BIM and a 3D model. In order to portray these misconceptions and to reveal in-depth understanding of the current design practices using tool and technology implementations, I proceeded with the data collection and analysis regarding the current extent of tool-oriented design practices. Hence, the first and most fundamental finding was that the tool implementation of the second case was far from that of a fully-fledged BIM.

The 'BIM' implementation, or more accurately the 3D model, was a bottom-up emergent strategy. Prior to this strategy, there was no strategy in place to deal with inter-organizational knowledge sharing problems. There was also no shared-software among the actors. In this emergent strategy, rather than using an information model, a draughtsman used existing software to create a 3D model suitable to facilitate the structural engineering crew. The engineers only used the graphic elements of the software package and did not implement the database model – which is the feature that distinguishes BIM from CAD systems. Calling a 3D model a BIM created a mismatch between the expectations of actors. The actors who initiated the model believed that they were implementing a BIM. Thus, the benefits gained from having the implemented model were much fewer than expected. Following this implementation, actors did not achieve the promises of better quality, less costs and a greater benefit for clients and end users (Otter et al. 2002; Eastman et al. 2008), although the use of the system externalized the responsibilities of actors by labelling the data and working on the design product in a multi-disciplinary way (Chao-Duivis, 2009). On reflection, the structural engineer's project leader understood that they had not actually implemented a BIM, but instead a 3D model:

"*...Well it is not a complete BIM perhaps. It is all set up on 3D, but the objects have their own properties, for instance steel amount; we just push the button and see how much amount of the steel. And now in particular for the major changes...*" (Lead Structural Engineer, 2008)

Beyond a self-reflection that states that the 3D model was not a BIM, the lead engineer also makes clear that the 3D model was only used within the structural engineering crew, leading to our second finding: The 'BIM'-strategy emerged in a single discipline and it was not adopted by other actors throughout the project. However, using the model switched the existing practice of the structural engineering crew from preparing 2D design drawings to designing in 3D.

Mintzberg et al. (2005) claim that emergent strategies arise in chaotic environments. The chaotic environment in which the 3D model emerged occurred while engineering organizations changed responsibilities and during the take-over processes within the design team. The engineering firm taking over the roles, and responsibilities and more importantly the design progress from the initial engineering firm was challenged by the need to understand and elaborate the design object that was developed by the first firm (Figure 52).

The intention behind the 3D model was to cope with the constant design changes occurring in the process of integrating the designs of the architectural and structural crews. In these fluid changes of design process, the draughtsman started a trial using a 3D model in which the existing drawings were submitted by the main design disciplines (i.e. architecture, structural, and HVAC engineering designs). The initial results of the 3D model revealed a significant number of mismatches between disciplinary solutions. These initial results convinced the design leader to use this 3D model as a main design tool. The structural engineering crew shifted their design method from 2D to 3D. Yet by following this shift, the managers in the structural engineering crew did not plan to use the 3D model as a new design tool in the design process. Regarding the design activity and managing the 3D model in the design process, the structural design crew led operations intuitively. Below I report on how this emergent strategy was developed and intuitively managed in the design process.

The left side of Figure 52 represents the two firms responsible for the overall design, the Architectural firm, and Engineering firm 1. The right side shows the two new engineering firms appointed by the client due to their expertise on buildings (Engineering firm 2) and signalling in transportation projects (Engineering firm 3), and that Engineering firm 2 replaced the position of Engineering firm 1. Firm 2 became responsible for the overall engineering services in the building design. Their service comprised structural design and HVAC engineering. The 3D model was initiated by this firm's structural engineering crew in 2009.

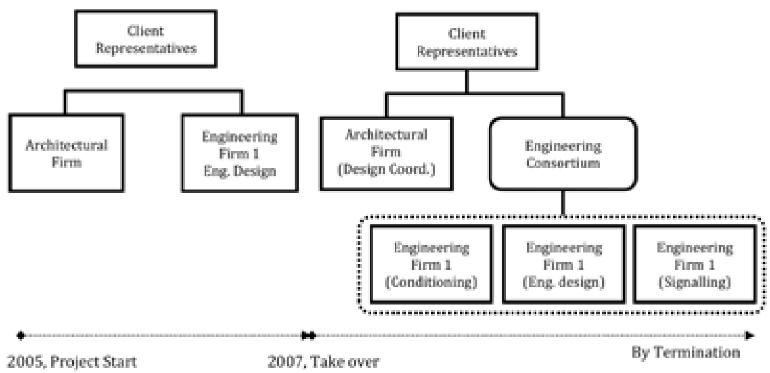


Figure 52

Organizational charts representing the differences between the organizational structure at project onset (2005) and the new structure introduced by the client in the middle of the design process (2007).

During the takeover process, engineering firm 2 needed to acquire a better understanding of the disciplinary components of this project (division of work), how these components of this large object were designed, and how they related to each other in order to form the main design object. The structural engineering crew attempted to achieve a better understanding of the project, as they were involved at the heart of the design process. On the one hand, crew members took over an on-going design process in order to move forward. On the other hand, the members tried to understand the components, the motivation of the architectural and engineering designs, and the goal of the projects while they were in charge of furthering the development of the current engineering design, while experiencing mismatches among the design solutions from different disciplines. The following statements give examples of one of these mismatches, which occurred across different disciplines.

"*...It* [the "80 cm" issue] *is still under discussion as to what was wrong there, because the tunnel it made is constructed there and someone came and measured that and they said well it is in the wrong place. And it is about the 80 cm. And the question is whether it is true...It is not clear who is to blame...*" (Executive Manager of the Client Team, 2010)

"...There are four housing blocks. One of the housing blocks was moved 80 centimetres, because there was a huge dispute about the zoning plan. The block would cross the zoning plan border by 80 centimetres. It is still unclear... [Finding out the error] *was approximately one year ago...We had to shift the complete housing block 80 centimetres... something else, which* [the dispute] *is still on going. I don't know how that is going to end. Personally, I have an opinion about it, but I don't know who will win it..." (*Project Manager of the Engineering consortium, 2010*)*

The executive manager and the project manager of the engineering consortium described the mismatches in the design process. This 80 cm problem shows the mismatch between design deliverables. This became the motivation behind developing the 3D model.

The draughtsman introduced the 3D model during the design process, at the point when the structural design crew (of which he was a member) was asked to re-design the structural design solutions. While this happened, the other disciplines continued to design, adjusting their designs to the new structural design.

When the design changes became unmanageable at a technical level, a draughtsman who worked in the structural design crew began to work in parallel to develop a 3D model in order to visualize formal design submissions in the preliminary design phase closure. This was an individual initiative of the draughtsman as he used the help of an intern. There was no official request from the lead designer or the managers. The draughtsman decided to develop a 3D model due to his previous positive experiences gained in his previous project. Together with the intern, the draughtsman started a pilot to visualize the overlaps between the official architecture and the structural engineering designs. The draughtsman described the intention behind the choice to use a 3D model:

"...I guess it was the first or the second day he [the intern] *started, he discovered that there is one column and that column does not continue, it is missing in one level. That was, how do you call it, the breaking point..."* (The Draughtsman initiated the 3D model, 2010)

In attempting to solve his own problem, the draughtsman turned an individual effort into a discipline-based strategy. Secondly, it illustrates how previous experiences can lead to initiatives that alter the current design methods. The strategy emerged at a technical level and was approved at the managerial level based on the argument that the new tool would provide benefits for the same number of person -hours. The draughtsman convinced his superiors that the new tool would save time rather than cause delays in the design process. Based on the negotiation which followed between the draughtsman, designers, and the lead engineer, the strategy was initiated on [date]. The following quote by the initiator of the 3D model shows how the design leader was 'convinced' regarding this change to design methods.

"...*We started with* [Sebeka –the first project combining 3D modelling and structural engineering]. *We calculated the hours as if we were working on 2D. When it was finished, we compared and saw that we spent the same amount of time in both programs* [referring to 3D and 2D software programs]. *But we have a nice model, so we could do a lot of things, when I started to work in* [Case 2] *soon after the Sebeka project. My only way of thinking was 3D, I want to do in 3D, so I needed to convince* [project leader of the structural engineering crew]..." (The Draughtsman initiated the 3D model, 2010)

The previous experiences of the draughtsman were on a small-scale project using a 3D CAD software package. The draughtsman negotiated with the lead designer about the value of the 3D model based on an estimation of the number of hours it took for someone to work with the 3D and the conventional design method.

The constant design changes, and the inconsistent design solutions which arose from the fact that the different crews worked simultaneously, emerged as a persistent and time-consuming problem. The team needed to find a way to integrate design changes and reduce inconsistencies. By comparing the results of hour/time estimation in 2D and 3D, the design leader changed their design method from the 2D to 3D format. The draughtsman who had initiated the BIM believed that the 3D model would achieve this goal. The management supported this idea as well. Yet, both the managers and the draughtsman did not plan the 3D model as a strategy nor did they anticipate the problems that this 3D model would cause.

The shift from working in 2D space to using the 3D model (therefore working in 3D space) was achieved spontaneously. This switch resulted in a change that was beyond being an intra-crew issue; it influenced the current way of designing, interacting and design representations within the design team. On the one hand, the draughtsman's initiative and its use as a bottom-up strategy were much appreciated as it represents the dialogue between 'bottom and up' levels in the project. On the other hand, the lack of anticipation regarding the consequences of using the 3D model, for example the direct use of the initiatives (without placing the initiative in a wider vision), represented limited view that resulted in overlooking the fact that the 3D model reflected a radical change in the design process. Therefore, Case 2 is an example of a bottom-up strategy, which lacks a visionary view within the current design practice. This problem is twofold: 1) evaluating the emergent initiatives and 2) using these initiatives directly in an on-going design process.

Case 2 revealed that the top-level actors did not thoroughly evaluate the initiative arising from the bottom level. The managers did not note that the draughtsman had experience in using a different software package on a different scale of projects. Therefore, the trial of the 3D model (in which the intern and the draughtsman were engaged) did not predict the advantages that could be had in Case 2. The trial was not sufficient to justify using the 3D model in Case 2. The experiences that led to using the 3D model in a LCBP were obtained during a smaller project (housing project) including the use of different software. The immediate benefits gained by rehearsing the tool did not provide the actors with a clear picture of how it could be used. Since the structural engineering crew had no experience in using the same software in 3D design, learning how to use the tool in an advanced manner was challenging. In a strategy that attempted to alter the design processes of the actors, one could expect that a transition phase would be needed which would give the actors time to familiarize themselves with the tool before using it on a daily basis. The familiarisation with the tool did not take place at the beginning of the design phase in which the design representation contained fewer details. The structural engineering crew had the expectations of the model, as the model would provide fast visualization and detailed representations. However, the model remained limited in fulfilling both expectations.

Case 2 revealed a managerial problem regarding how to juggle the current mismatches in the design solutions, and how to understand the large complex design object thoroughly and promptly, and to evaluate the emergent strategies in regard to whether they would respond to these current mismatches. In the end, the 3D model resulted in additional problems for the design team and it remained a mono-disciplinary tool for the structural engineering crew. Below we report on the 3D model's potential as a KSS. Since the focal point of this case was BIM, the first dimension to be explored is the tools.

§ 5.3.1.1 Tools

Tools within a KSS represent a digital platform in which multi-disciplinary design information is created, accessed, and shared, and the design 'object' comprising multi-disciplinary design information is visualised. If used consistently, tools provide accurate and up-to-date design information that is accessible for each member participating in BIM in order to facilitate the coherent interpretation of design objects.

In order to benefit from the full potential of tools, the choice of software package, the timing of implementation, the identification of the tools' purposes, and the commitment among the participant organizations are all key success factors. Below, both the implementations and the way that people responded to these issues are elaborated.

A Different Time Perception of Actors

The implementation of the 3D model was delayed in the Case 2 process. Therefore, other parties were not involved in using the new 3D model. This raises the question; when should a strategy be implemented 'on time' so that the actors can embrace this new tool.

The data analysis showed that design team organizations have different perceptions towards the timeline of the project; they regard a project as starting from the point in which they become involved.

Since the design was already in the definitive phase (interchangeably called the final stage) when the model was introduced, the other parties (in particular the architectural firm) already had their design drawings placed in 2D formats. These parties were not willing to change their 'weapon' with which they felt comfortable when conducting their design work, externalizing their knowledge, and preparing their design representation. When the structural engineers introduced a 'new weapon', other actors remained reluctant. The actors in the firm of architects did not see any advantage to changing their tools during that particular point in time of the project; changing the tool would mean altering their current design method.

"...*At a certain point* [Engineering Firm 2] *came just with the model, and we have already made a lot of 2D drawings* [Project Architect 2]. *So a lot of sections* [Project Architect 3] *yeah, a lot of sections* [Project Architect 2], *so it was already too late* ..." (Group Interview of the Project Architects, 2010)

In this quote, the project architects show their objections to introducing a new tool in the middle of the design process. They justified their non-participation in the 3D model as their design deliverables had already been detailed in 2D space. Other actors such as the architectural crew stressed that they had worked for four years with their software or tools (i.e. AutoCAD, MicroStation etc.), and using the 3D model would mean starting the design representation from scratch. This change did not attract the actors in committing to the 3D model, particularly when the change would occur in the middle of the design process. Each organization that had taken part in the project from the onset until the introduction of the 3D model had already achieved an extent of design understanding due to working from the onset. The outcomes of the design organizations were 2D drawings, documents, etc. This meant that the organizations initially involved in the design process had a 'design history'. The design had been developed from existing design drawings that were taken from the onset to the current stage. The old drawings became the base for new phases and their development requirements. This automatically resulted in a design history that could be retrieved manually if the actors needed to review the decisions previously made and the design solutions.

Changing their 'tool' during the project was seen as a constraint since this design history could not be retrieved when necessary. As Engineering Firm 2 had only become involved during the middle of the design process, their experience was different. On the one hand, as it was a starting point, using a new tool was appropriate for the structural engineers. On the other hand, the crew did not engage in generating concepts collaboratively with the architectural firm from the onset of the project. Their understanding required a retrospective approach, in which the structural engineers needed to look and interpret the 2D design deliverables and, sketches that had been prepared beforehand. This interpretation was open to misperceptions and understanding, since it demanded an understanding of how the disciplinary components of these objects were divided (division of work), how these components of the overall object were designed, and how these components came together to form the main design object that reveals the main design solution. The interpretations through 2D deliverables required 'mental modelling' by the design crew in order to comprehend the overall project design that inter-connected the division of work within disciplines.

"...*It is marvellous to work in 3D. We* [referring to the lead engineer and himself] *had a big argument about it* [the model]. *In 2D we did not see the problems, you think that the building is in your head but you miss something, and then he was modelling it* [the current design]*, and it came out a mess...*" (Draughtsman initiated the 3D model, 2009)

"...*The building was already in our heads... It* [any 3D model/BIM] *makes it* [the design work]*even harder...*" *(Project Architect 1, 2010)*

"...*The aim is that the 3D model was to provide better insight into the project. Some people say that it was very useful but well, yeah, I did not use it...*" (Executive Project Manager –the Client), *2010)*

"...*It* [the 3D model] *looks very good and it was very easy to have a closer look...*" (Lead Structural Engineering, 2010*)*

The quotes of the four actors reveal the different perceptions towards the 3D model and BIM. They project the differences between 'modelling' the design object, as architects were comfortable with what was in their 'heads', whereas the engineering disciplines (including the client's representative) praised the potential of the 3D models The common ground was that the actors, who either praised or were reluctant to use these tools, did not have real experience working with a 3D model and BIM. The structural engineering crew's model used the software properties, rather than the introduction of a 'model' to enable multiple entries for design inputs with shared-databases.

The motivation provided by the structural engineering team for making the design process smoother and improving the comfort of the other actors who pursued their 2D design practice gives rise to two questions. How did the other actors sustain accuracy within their design crews, more importantly within the design team, since these models are highly individual efforts and in the 'heads' of the designers? What made the other actors reluctant to use the new promising design tool? In Figure 53, I describe how the other actors facilitated their interpretation of the 2D design deliverables.

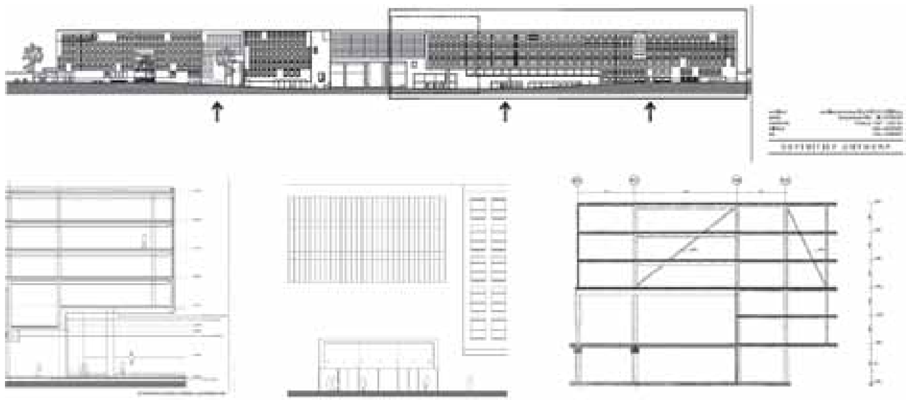


Figure 53
Official submissions by the architectural firm (top, left and the centre) and by the structural engineering crew (right). They show 2D design representations, and they depict how the project was 'modelled' in 3D based on these representations.

B Unsynchronized Organizational Tools

In the data analysis, different initiatives were found to support a 'shared and accurate' design model for designers. These initiatives resulted in different 3D models providing different 3D representations of the project. However, these models were 'organizational assets' and they were not shared with others except for some general illustrations such as those shown in Figure 54. As an example of these models, the architectural firm contracted a free-lance company to prepare 3D images. These images contained the architectural design of the project which showed what the actual building would look like and its relation with the surroundings in the project's location. These 3D images supported an understanding of the overall design of the project, yet remained limited to illustrating the nature of the structures and the inter-connections of divisions (interfaces).

Figure 54
Case 2 3D images prepared by a free-lance company

Another example was provided by the client team. In 2009, the client team appointed an organization experienced in BIM systems in order to have a BIM for clash detection. This 'real' BIM effort was only used for a specific moment during the project to see how each building component came together and whether there were any mismatches. This meant that the client initiated BIM software solely for static use (as it only used to visualise the building in 3D format and not as an interactive design tool for the design team). Both examples reveal that each organization had their own 3D model, either for one-time use or to continuously support their understanding of the large complex design object. These different models show that different tools had been used to achieve the same purpose (a better understanding of the project using 3D). Yet, these tools were not shared by the actors and they never became a part of their design processes.

C Unattractive Properties of the 3D Model for Architectural and HVAC crews

In the analysis of the data, we found several reasons why the 3D model did not attract the other parties. These reasons had technical, social, and practical aspects.

One of the technical reasons given was that the structural engineering crew had a rehearsal model from which the design leader and the crewmembers were aware of the mismatches in the existing design objects. The problem was that this was a study-model and contained technical errors due to the inexperience of the users (i.e. the draughtsman and the intern). The draughtsman's previous experiences were based on a different program in 'Sebeka', and he and his intern 'learnt' to use the Bentley software through modelling the design in 3D. In this learning process, the study-model inevitably contained errors that had been overlooked during the rehearsal process. However, when the crew started to use the study-model as a main design representation, they inevitably proceeded with the overlooked errors embedded in the model. The structural crew were constrained by the inclusion of these errors as they further developed the design object.

Another technical reason for the non-use of the 3D model by other actors is the low-quality output of the 3D model. The 3D model was not a specific information model; it was developed by the structural engineering crew by using the 3D properties of their existing software package. The structural engineering crew did not evaluate the quality of the outputs of the 3D model in comparison with the level of the design representation. In other words, the outputs of the 3D model demanded an extra process in which the engineers developed the outputs and leveraged their level of detail with regard to the design information. The low quality output resulted in the designers spending extra effort on detail and making the deliverables presentable, as illustrated in Figure 55a The outputs of the 3D model required another 'manufacturing' process so that engineers could prepare a meaningful artefact that embedded sufficient and coherent design information. In this process, the engineers detailed their design documents manually, and they elaborated on the design messages destined for the other parties so that the necessary design information could be provided (See Figure 55b). However, this 'manufacturing' process was time-consuming and challenged the interactions of design team members, since the preparation of the design deliverables required more time. Because the output quality was low and the model was time-consuming, the other parties (in particular the architectural firm) were not encouraged to use or benefit from the 3D model in the design process.

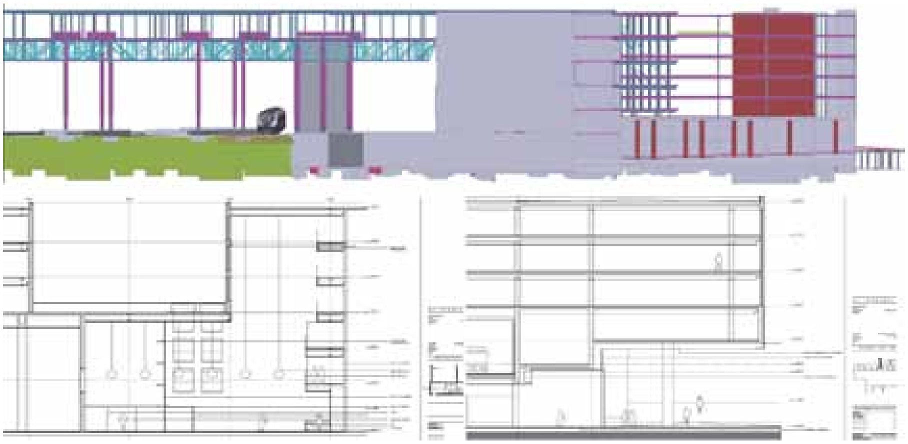


Figure 55
Figure 55a (upper) Example of the outputs of the 3D model
Figure 55b (lower) Design deliverables that needed manual editing

Another technical problem was that the 3D model did not allow multiple-entry; only one designer could add, edit the design input, and model the design object. This mono-entry feature of the 3D model constrained the parallel processes within and across the design crews. By accepting the 3D model as a new design method, the actors actually hindered their simultaneous design processes when working on different divisions of the project. This technical problem resulted in a social problem, which affected the design crew's interaction with the overall design team, and their parallel and dependent design processes.

The 3D model added a social problem to the structural design crew. The model did not have the capacity to provide multi-user contribution. It became dependent on one specific individual to work at one time, which altered the way that the crew members worked simultaneously. This person was the draughtsman who added the overall design information (gathered from the disciplines) of the all the divided design parts of the project, and modelled them individually. This modelling required a 'loop' between engineers and the draughtsman (3D modeller). Firstly, the engineers needed to provide their design inputs by gathering the design information from the other disciplines. Once they had prepared the calculations and the structural design, the inputs were transferred to the draughtsman who then could update the model through visualising the design information transferred by the engineers. Following the updated model, the extractions were made (these extractions form the basis for the formal design representations/ deliverables). As illustrated in Figure 56, the 2D extractions of the 3D model needed manual effort by the structural engineers so that these design deliverables contained sufficient information for use by the other actors.

Figure 56
A 2D extraction as output of the 3D model

The structural engineers developed these low quality extractions to become formal design deliverables for submission to the parties involved. In this recursive loop between design-modelling-representation processes, the structural engineers remained dependent on one person who had to update the model. This dependency hindered the simultaneous working processes as in the conventional method (working 2D), where the designers could elaborate their divided design solutions within their focused working areas. This recursive loop caused difficulty in the simultaneous design process of the structural engineering crew and resulted in delays in the design team. Therefore, the tool that had been initiated to tackle the design changes in Case 2, became an obstacle for the design team. Figure 57 illustrates this dependency between the designers in regard to the 3D model. As shown, the draughtsman was responsible for all the inputs coming from the structural engineers who exchanged the design information with the other disciplines.

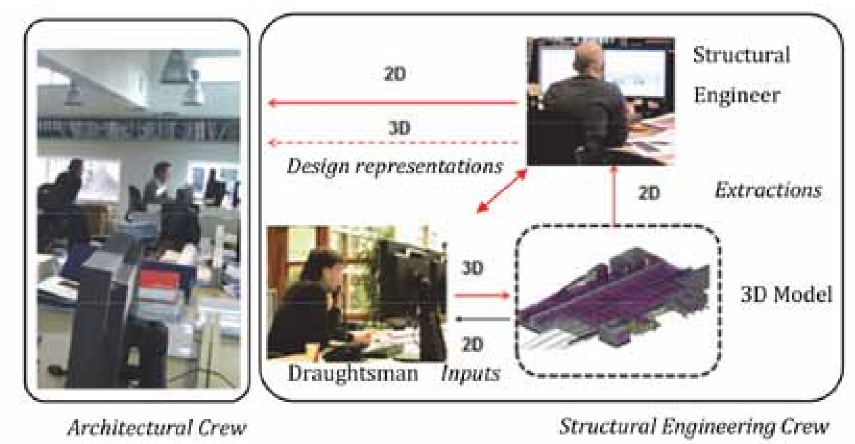


Figure 57
3D model use within the design process

The structural engineer shown in Figure 57 could continue on his design task and interact with the other disciplines. This means that re-distributed design objects (as extractions) still carried a danger of being non-overlapped until the merging had been completed within the 3D model. This working in both 3D (one-man dependent) and 2D (where multiple designers continued working simultaneously in the divided work) resulted in mismatches between both the disciplinary and multi-disciplinary design. The mismatches in design deliverables were evident in the interfaces of the sub-divided design parts.

"…We leave it [the 3D model] *unspecific and more specific drawings supports. Yes, most of the time you have column with a node, and or something beam on it. When you model all the nodes, you must do too many things. So we give one details and we don't update all the columns or make them too detailed. So if you see it on a 2D plan, you see one dot and that is column, so in 3D also, but how the connection is made, it states in the detail drawings…"* (The Draughtsman initiated the 3D, 2010*)*

This quote by the draughtsman shows how the 3D model was used in the design process with regards to design representation and its development over the course of time. It also reveals that the 3D model required energy and the structural engineering crew did not update every design change (as the draughtsman discusses by giving an example of the column). In the end, the structural designers applied design changes to their 2D drawings, but not to the 3D model. Thus, the 2D drawings embedded the most recent information. However, the initial aims of the draughtsman were not met, as the 3D model had not been updated. The structural design crew had two different versions of the design object; one in 2D space (where designers manually applied design changes) and one in 3D space (which was updated periodically by the draughtsman).

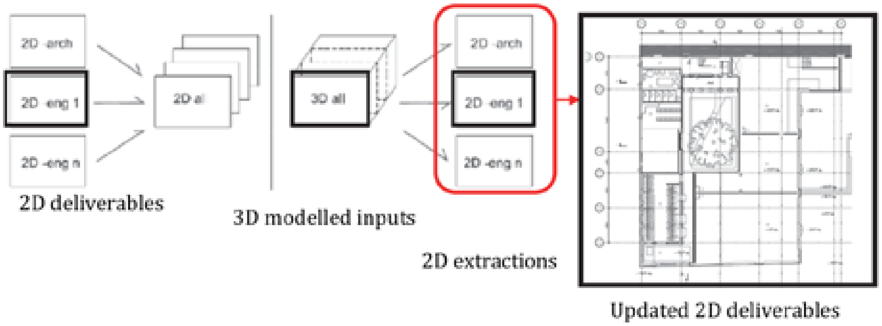


Figure 58
Design representation in both traditional and 3D model formats.

As an example, when a structural engineer needed to have a section to respond to the most recent inputs received from other disciplines, firstly, the draughtsman needed to update the model. This re-modelling included the most recent design inputs. After the draughtsman had updated the model, he then provided the 2D extractions for the section needed by the designer. These were low-quality extractions to be used as a basis for drawing the section. The structural engineers received this 'basis section' and manually detailed it to prepare sufficient and coherent design information. Then the deliverables were sent to the architects. This re-modelling/extracting/manual editing loop was required for any design change. However, time pressure did not enable the structural designers to update every single design change, as this loop was time consuming and therefore delays in interacting with the overall design team were the result. In order to match the speed of the design process of other actors, the structural design crew stopped updating the model for small changes. The engineers only updated the 2D deliverables. However, the result of this was that the 3D modelled design object became derailed from the design process and became the source of the initial design team situation where there were design mismatches amongst the actors' design deliverables. In the end, the use of the 3D model ended at the point where the structural design crew had started.

In Figure 58, the rectangles represent the design precedents of each discipline and their format (2D or 3D). The disciplinary precedents represent official sub-design solutions of the large and complex design task. The left side of figure illustrates the conventional method where designers present their design solutions in 2D format. In order to achieve a 'meaningful whole', the 2D representations were overlapped. The right side of the figure illustrates the actual use of the 3D model. The structural engineering crew visualized their design product on the model. Yet, the design dialogues were mainly based on the 2D outputs. Hence, the overlap between divisions was performed manually as it occurred using the conventional method. The structural engineers used ad hoc design dialogues to check the adequacy of the model, as the modelling was done by the draftsman (See Figure 59a). After synthesizing their ideas and design solutions, the engineers prepared their 2D drawings, when they were 'back' to their working spot. Figure 59b portrays the moment that the structural engineering crews work in a focused environment to prepare their outputs to the overall design solution.


Figure 59
Figure 59a (Left image) Draughtsman working on the 3D model supervised by two structural engineers, Figure 59b (Right image) Focused-working environment of the structural engineer.

D Limited use in ad hoc design conversations

In addition to the technical and social problems experienced with the 3D model by the design team, there was a practical reason for the model not being attractive for other parties. The 3D model was not able to respond to prompt design solutions of the other actors; it was slow in maintaining the tempo of the other actors' design practices. In the tool-implemented design environment, immediate artefacts required prompt solutions (or design ideas) from the design team in order to understand design problems/ solutions. The model was not suitable for ad hoc conversations in which immediate sketches needed to be exchanged. Preparation of these artefacts required a large number of hours (working energy) to reach a level where the extractions could be used as formal design representations. Due to the one-man dependency and the need for elaborating the extractions, the model remained of limited value for day-to-day interactions and/ or responding an immediate problem solving process across the design crews. These immediate exchanges of the design information to resolve design problems were often done by e-mails, and supported afterwards by phone calls. In a situation where more alternative design solutions were needed, preparing these alternatives meant that the structural engineers needed to update the model many times. In a large complex project where different designers were in charge of sub-divided design solutions for a number of alternatives, it appears that using the 3D model in these sketch-based discussions slowed down the design process. Therefore, the design team members did the following: they prepared hand-drawn sketches or edited existing 2D design deliverables rather than updating the 3D model and seeing the design alternatives in 3D format. The following quotes show the appreciation of the computer-mediated design sketches by design team members:

"…Architects are often draughtsman as well, so they draw on their computer easily and send it to you. But always by email. I made hand-drawn sketches and later I made some digital sketches, because you can communicate more easily…[In return] *they* [the architects] *still send drawings; that already was neat and that became even neater…"* (The Chief Structural Engineer, 2010)

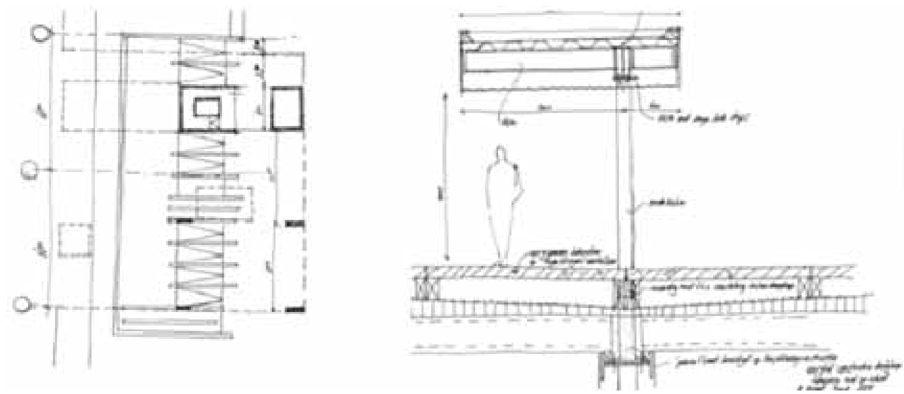


Figure 60
Sketches attached to the e-mail conversations between the structural engineering and architectural crew.

The chief engineer praises the ability and the speed of the architects when preparing design alternatives using computer-mediated sketches. The quote reveals the interaction through e-mails and sketches to clarify the design problems/solutions. It highlights the differences between the design representation of the architects and the structural engineers. The two different actors' artefacts are illustrated in Figure 60. The project architects were able to prepare and send 'neat drawings' using a tool that they 'could draw with their eyes closed'. Thus, in the end, the 3D model was only updated when the design solutions were final, which meant that the 3D model was not always synchronous with the actual design process.

The reason was twofold: firstly, partial representations, hand-drawn sketches consumed less designer time and were therefore preferred by designers and encouraged by lead designers. The second reason was specific to the 3D model. When there was a change in the design, the 3D model required new input and processing of this input so that the partial design representation could be provided. Unlike any 2D program, this change was applied to the overall 3D model, as this was the model's greatest advantage. Yet this change required long processing of the inputs. These partial artefacts were developed to support ad hoc design conversations and to inform the other parties with the proposed solution and often did not refer to the final design solutions. This meant that the actors first discussed and exchanged their design solution through sketches, then agreed on a final solution in which cross-disciplinary design requirements had been met. This process required quick responses that needed to be sent back and forth between actors. The 3D model was not suitable for these ad hoc conversations, since updating the model required a significant period for processing the design inputs. The frequency of interaction in relation to the necessity for having drawn sketches challenged the value of the 3D model in the design process, as illustrated in Table 7

The lead structural engineer attempted to stop the use of the 3D model due to the long chain of interactions and dependency on the draughtsman who updated it. When a problem occurred in the model, there was a 'domino-effect', which interrupted the design, and the interaction between other actors. This resulted in conflicts between the technical level and the managerial level representatives. The main conflict was based on two choices:

1. Stop using the 3D model, which would deem the time spent on initiation and elaboration of the model sunk cost
2. Continue using the model with the necessity for further development, in that way designers and managers gain more experience by using the model

The second choice was implemented.

Date	From	To	Time
14-3-2008	Architects	Structural Engineers	17:30
14-3-2008	Structural Engineers	Architects	17:01
14-3-2008	Structural Engineers	Architects	14:59
14-3-2008	Architects	Structural Engineers	13:32
14-3-2008	Architects	Structural Engineers	12:14
14-3-2008	Structural Engineers	Architects	12:09
14-3-2008	Architects	Structural Engineers	11:13
13-3-2008	Architects	Structural Engineers	15:12
13-3-2008	Architects	Structural Engineers	13:36
12-3-2008	Architects	Structural Engineers	17:26
12-3-2008	Architects	Structural Engineers	17:13
12-3-2008	Structural Engineers	Architects	17:13
12-3-2008	Architects	Structural Engineers	12:31
12-3-2008	Structural Engineers	Architects	10:43
12-3-2008	Structural Engineers	Architects	9:35
12-3-2008	Architects	Structural Engineers	9:19

>>>

Date	From	To	Time
11-3-2008	Architects	Structural Engineers	15:24
11-3-2008	Architects	Structural Engineers	10:11
11-3-2008	Architects	Structural Engineers	10:10

Table 7

E-mail exchange frequency between structural engineering and architectural crew in four days

"... [The project leader of the structural engineering crew] *was not happy with the BIM used in the* [Case 2]. [Bram] *mentions that the BIM used in the* [transportation project] *is difficult because of the software packages used*. [Hans], []ohn], *and* [Peter] *are involved in a discussion concerning the use of other software packages...*" (Diary note, 10 September 2010)

The following quote illustrates the challenges of using the new tool in the design process and a conflict between the initiator and the project leader.

"... [Project leader of the structural engineering crew] *came and stopped us and said two or three times, and said 'ok now we will continue in 2D'. Then I got angry, and wanted to keep it* [the 3D model], *because when you leave it, it became worthless again. I wanted to have this 3D accurate, the 3D principle. If you go back again* [in] *2D, it is worthless, it is lost. You can throw away all the efforts ...*" (The Draughtsman initiated the 3D model, 2010)

The statement by the draughtsman reveals the conflict between the draughtsman and the project leader regarding the continuity of the 3D model and that stopping the process would cause more loss than it would provide benefits. It also highlights the issue of introducing a new tool: the effects of the introduction of tools on the current design practices need to be well planned.

In 2010, the deadline issued to the client for official design submissions could not be met due to the technical errors that occurred in the model. Therefore, the structural design crew had to wait until the model had been restored. Consequently, the structural design crew delayed submitting their documents to the client.

E Limited Influence of the 3D outputs in Inter-organizational Interactions

Even though the 3D model did not become a collaborative design tool within the design team, it did influence the design team interaction. Other parties, mainly the architectural crew, benefited from receiving the '3D PDF' [an output style where the rotational movements can be done but not in scale]. However, the actors only used these 3D illustrations for design discussions. Except for these particular moments, the 3D model outcomes did not become part of the design team process. Actors did not combine the outputs of the 3D model with the official design deliverables, and did not regularly bring these outputs along to the meetings regularly. The 'design space' of actors remained in 2D as illustrated by the image of an inter-disciplinary meeting between architects and structural engineers shown in Figure 61.

Figure 61
Inter-disciplinary meeting held between the architectural and structural engineering crews showing the use of 2D artefacts (a screenshot from the video recorded in the meeting)

This case illustrates that the design practice was partially supported by different tools. The 3D model did not change the conventional design method of knowledge representation using the 2D design deliverables. Except for the structural design crew, the actors who had worked on 2D design space attempted to construct a full 3D picture in their mind. By not embedding the 3D model in the design process, actors missed an opportunity to provide a better understanding of each other's design solutions, since 3D visualizations have a great potential for enabling the design information to be interpreted. The actors (i.e. architects, HVAC engineers) continued to receive 2D design objects from the structural engineering crew and interpreted the design objects by using conventional methods and constructing the 3D image in their mind.

Understanding a design of a large complex project is not always easy and necessitates additional support. Interestingly, the firm of architects and the client team both used 3D models, in spite of the fact that a 3D model was available from the structural engineering crew. The architectural firm hired a free-lance organization to provide 3D visuals in order to achieve a 'reality check' between the indented design represented in 2D and the 'actual' representation in 3D. However, these efforts were not correlated with the 3D model made by the structural engineering crew. Similarly, ProM (the client team project management company) asked an external party to develop a BIM for clash detection.

§ 5.3.1.2 Procedures

We investigated the explicit and implicit rules in this tool-oriented design environment. Explicit rules related to tools refer to the sets of norms that regulated the use of a 3D model in Case 2. In addition to the 3D model-focused rules, explicit rules include contractual arrangements that influence the interactions of design team such as planning and implementation of the physical settings for social practices. Implicit rules refer to the intuitively shared routines of the design team members. Design team members may not be fully aware of the types of rules they follow. These rules are important for portraying the design and interaction habits of the design team in order to evaluate the strengths and weaknesses of the design team when using tool-oriented implementations. Firstly, the rules within the design team (including those of 3D model use) are reported. Then the client and design team rules are discussed.

A Rules for tools

During the data analysis, I was not able to find any explicit rule that would define and regulate implementations for managing the 3D model as a strategy. The actors in the structural engineering crew intuitively planned their implementations from the initiation moment by the draughtsman to the moment when design leader agreed to implementation. The design leader of the structural design crew approved the use of the 3D model spontaneously; no review was conducted showing the relevance of the draughtsman's previous experience in regard to the new setting of this large complex project. Furthermore, there was no systematic evaluation of the 3D model after it had been implemented by the structural engineering crew. The 3D model was not evaluated systematically over time to see whether it had fulfilled the implementations. I could not find any internal or external document that identified changes that had been made to the structural engineering crew's current design practices.

Although I found no rules regulating the 3D model as a strategy, I was able to find a rule for the development of the 2D extractions from the 3D model. This rule was only implemented for the structural engineering crew that needed to work on the 2D extractions in order to add comments and notes to the drawings before sending them to the other crews. These comments and notes were added to clarify and point out the issues visually' on the drawings. This rule was called 'rules for adding annotations in the drawings'. As shown in Figure 62, the rules contained visual instructions to make sure structural designers correctly followed the steps when adding comments and remarks to their drawings.

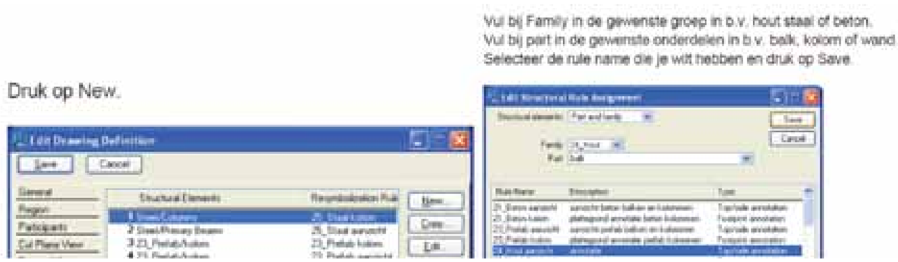


Figure 62

Two screen shots showing the visual instructions of the rules for adding comments and notes to drawings in Dutch.

Except for these internal rules for drawings, I was not able to find any change in procedures that explicitly identified the design interactions, design communications, or the exchange of design information for a 3D model-supported design process (both in the virtual and shared-physical settings). The inability to access explicit rules highlights a concern regarding the awareness of actors with respect to formalizing internal interactions (among actors), the exchange of boundary objects, and defining and exploiting the benefits of the 3D model within the design team. Since the structural engineering crew did not deliberately exploit the potentials and planned actions with regards to the 3D model use, the crew members, in particular the design leader, were not able to promote the use of 3D model to other actors. The other actors perceived the structural design crew to be struggling with a new tool and therefore the actors became reluctant to use the 3D model. As a result, the model and the 3D visualizations were not included in the design conversations, interactions, and exchange of formal and informal design precedents within the design team. The use of the 3D model in the design team was therefore limited to the 3D PDF files created for the other crews based on ad hoc requests.

During my investigation, I could not find any particular agreement between the design team organizations that regulated the long period of working together. No shared software was established at the onset of the project by either the client team or as a request from the design organizations. The design team organizations kept working with their own software packages. Using different packages required a conversion of data and documents, and it constrained the speed of accessing and overlapping the design information, and increased the possibility of data loss during the conversion processes. Even though the design team organizations worked together for a long time, they did not invest in building a digital infrastructure that would aid their design process.

B Rules for formal interactions between design and client teams

Client and design team interactions were more explicitly regulated in Case 2 than in Case 1. Exchange of design information was planned by setting the design deliverables in each phase based on the milestones set by the clients. The design teams defined their interactions based on the two project schedules; the first encapsulated the design organizations and the client submissions, and the second project schedule was used to define what was to be submitted. The former was for the overall design team, whereas the second project schedule was only for to be used by the three firms of the engineering consortium.

Figure 63
Shared-planning between the engineering consortium and the architectural firm

The project schedule was the major source of rules for design team interactions, as it contained the official submissions of the design deliverables of the design team. These two official documents served to describe the interaction procedure. The first document was the project schedule that identified the issues as follows:

1. the design phases
2. the milestones (official submissions within the design team and to the client team)
3. the design organizations required to submit the deliverables, the time period (this defined the working period of each design organization)
4. the division of work (such as submitting the sub-design packages).

The second document was called 'the project product list'. It contained detailed information on the submissions of the work divisions. The list clarified the representation of design and content information. The representation information refers to the scale of the submissions. The content information was for clarifying the format of the submission such as reports, drawings, the responsible design crews, and the design leaders who were responsible for the submission acts. These two documents (Figure 63and Figure 64) were cross-referenced as a result of the submission requirements at each phase of the design. In doing so, they established the rules for design precedents.

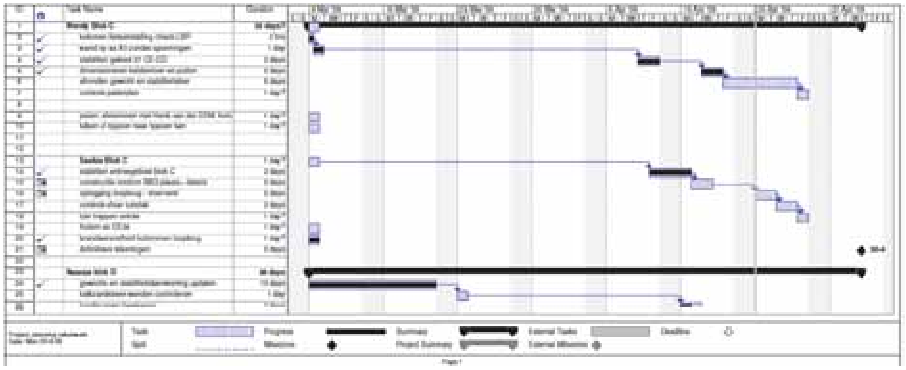


Figure 64
Design process planning for the structural engineering crew based on client team milestones

In addition to this cross-referenced interaction definition, an implicit rule was followed by the design team organizations; that there was to be an expected increase in the interactions between design team members prior to the client's deadline. The interactions accelerated in both distant and shared-environments. Thus, the milestones were the main determinants for planning the frequency of the meetings and the distance-interactions such as e-mails and phone calls for design conversations. Below, the rules for interactions (both physical settings and distant work islands) are given.

C Rules for social interactions and exchanging design information

In the design team interactions, face-to-face and distant organizations were highly influenced by the organizational practice of architectural firm, which became responsible for the overall design coordination for the takeover of the engineering firms. This new role as a coordinator was shaped by the organizational practices of the architectural firm and it resulted in an autocratic design environment in regard to the way that interactions were performed. These interactions were neither pre-planned nor explicit. However, the interactions were dominated by the closed-off nature of the firm. An example of this closed-off nature can be seen in the practice of the firm in regard to distance-interactions of other parties.

The lead architect established one single, shared e-mail account for the overall design organization's communications and interactions. The architectural crew performed all the distant dialogues using this one account so that the lead architect and the other crew members would be aware of the discussions between actors. It should be stressed that being aware of all the discussions resulted in an open design environment. However, based on the observation of the architects, one account resulted in a controlled-design environment in which each word of design crew was observed by the others and by the design leader. Rather than being an open environment, it resulted in an autocratic environment where interactions were architecture-centred rather than aimed at creating a collaborative working environment.

Due to their implementations, the engineering firms perceived and treated the firm as 'the difficult party', dominating and ruling the overall design process. In particular, the structural engineers claimed that they found themselves in a project environment where the architectural firm was in the lead, and the rest of the team became the design 'followers' rather than collaborators. In other words, even though there was no official hierarchical structure within the design team, the firm of architect's practice resulted in a self-demarcated design environment that regulated both distant and face-to-face interactions. Within this self-demarcated design environment, interactions were still irregular, deadline-dependent, and ad hoc. The majority of the face-to-face interactions resulted from organizing physical settings. These settings were implicitly shared by the design team organizations.

D Rules for formal interactions

To evaluate interaction in the physical settings, I investigated the planning and execution rules regulating meetings, in which design team organizations reasoned their practice in the same physical settings. The components of 1) disciplines and their representatives as attendees 2) the content, 4) the timing/ frequency and 5) location were investigated.

As mentioned previously, the lead architect was the design coordinator and therefore, it was the party that organized the settings. The lead architect and crew members determined the content of the discussions, prepared the agenda and selected the disciplines to be invited. The disciplines were intuitively chosen to be present in the settings which often resulted in conflicts between crew leaders, since there was no plan for them to predict the occurrences of the meetings or be aware of the ones to which they were not invited. The majority of the inter-disciplinary meetings contained two discipline leaders and their crews. There was an unwritten rule that each leader brought three designers/engineers along to the meetings. These three designers represented the three main divisions of the project (housing, offices, parking). The division of work formed the interactions across the participant disciplines. The content of the meeting was pre-defined by the architectural crew. It was sent, exchanged, and commented on via e-mails. Defining the issues for a meeting was called the 'Concept Agenda' process. Each discipline had a chance to add to the agenda sent by the architectural crew. Each discipline was responsible for bringing relevant artefacts that were required to discuss/ resolve the issues in the agenda. The architectural crew divided the overall meeting into time slots. In each time slot, the participant actors focused on either the general problems (managerial) and/or one division of the project. Meetings were always held in the architectural firm's office.

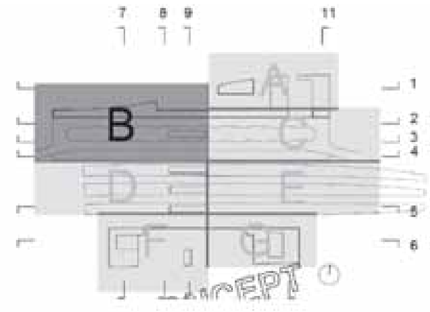
The frequency of the design coordination meetings was not pre-defined. There was a shared assumption that prior to the milestones, the frequency would increase. However, there was no clear scheme for the meetings and their participants. An analysis of the e-mails and the agendas of these meetings revealed there was no clear structure on planning the participants as being periodic or in a continuum. Meetings and the actors attending them were irregular. This irregularity had a negative influence on the continuity of social interactions between the disciplines and resulted in intermittent environments, which contained dialogues that resolved design issues based on the divisions. Since actors did not have an overview of who met with whom, when, and what was discussed, the synchronization of the design became problematic. Furthermore, although there was a shared rule, the problem of these implicitly run meetings resulted. I was unable to identify a clear approach that would transfer the decisions/discussions taken during the meetings to the actors who were not invited. The participants captured the decisions and discussions individually. This resulted in various interpretations of the dialogues that were being carried out in the same environment. The actors who participated were occasionally not informed about the status of the design. Not all of the actors were kept up to date about changes and improved/changed design solutions. Thus, de-synchronisation became inevitable in the design processes.

Figure 65
Figure 65a (left) The minutes of a managerial-level meetings
Figure 65b (right) the minutes of design meeting between the architects and the engineers

Another concern about the meetings and their outcomes was that the minutes became the interpreted versions of the design discussions and decisions. There were no official minutes that the parties exchanged and approved; instead everyone took individual notes, which could contain false information. The structural engineering crew formulated a 'rule' to overcome possible misinterpretation by discussing the roles and tasks in the light of the design issues resolved during the meetings. The structural engineering crew conducted a post-meeting disciplinary conversation after each inter-organizational meeting (see Figure 66). This was a disciplinary meeting and enabled control of the minutes, a redistribution of responsibilities, and an exchange of design discussions/decisions taken in the inter-disciplinary meetings. However, we observed that only the structural engineering crew had an explicit rule for conducting a disciplinary meeting to reassign tasks and discuss the minutes. The other disciplines left this exchange to informal interactions that occurred naturally between crew members on their distant work islands. The differing styles of minutes and taken decisions are illustrated in Figure 65a and Figure 65b.

Figure 66
Figure 66a (left) Inter-organizational meeting of the design team
Figure 66b (right) Post-meeting conversations of the structural engineering crew

This resulted in another problem; no rules were set for keeping track of the design process as no rule was in place to keep track of the evolution of the two main objects. Since the minutes of meetings were kept irregularly and in different formats (hand-written, digital texts etc.), this posed a challenge to keeping a record of the design process. The meeting minutes (containing design discussions, changes, and decisions taken) were kept irregularly and were an insufficient means for rendering the project's history when needed. Examples of this need are 'not-remembering' why the current design solution was at a certain status, and what the design reasoning was in the case where the current design solution might be problematic for actors. In other words, there was no regulation for keeping and managing the inputs of the meetings between client design team; from both sides of the design and client team organizations.



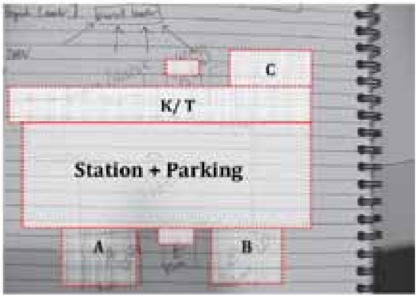


Figure 67
Figure 67a (left) The division of work in the project: scheme for the design deliverables
Figure 67b (right) The decomposition of the projects drawn by a project engineer

The implicit rules of interactions in both distant and shared-settings demonstrate that the division of work is a crucial factor that influences social interactions and design conversations between design team members. The division of work was reflected by the use of tools, distant-interactions, and interactions within physical settings. Yet, no explicit attention was paid to defining the division of work in the project. Each discipline 'divided' the overall design problem individually, yet their divisions overlapped, as they were based on functional components of the project (see Figure 67a and Figure 67b). This exposed the shared mind-set of the design team organizations towards perceiving and managing the overall design object. In this perception, actors used the functional project division to divide the responsibilities among their crews. Even though this division of responsibilities within each crew overlapped, the interfaces among the divisions became under-emphasized and therefore problematic in each crew. The meetings included efforts to discuss the interfaces, yet these discussions were not deliberately planned.

§ 5.3.1.3 Physical Settings

In the physical setting dimension, the questions to be answered are related to the role of physical settings in a 3D supported design process; were there any organized settings that supported the knowledge sharing processes of actors? In the analysis of the data, two types of social practices that encompass physical settings were found; meetings and design workshops.

A Meetings as physical settings for social practices

The design team organizations planned physical settings by organizing meetings. These meetings represented short-term intermittent events. The planning and implementation efforts of the physical settings were in different levels. The first level was between the design and client team ('managerial'). The second level was within the design team, in which the lead designers/engineers were representatives. In these meetings, the 3D model did not have a significant impact on any component of the physical settings, except that the actors used the outputs of the model for resolving critical design issues.

The components of meetings were: a) participants, b) duration, c) frequency, and d) content definitions. In relation to the question above, data analysis showed that the 3D model did not change the occurrences and planning of these physical settings, compared to the settings organized prior to the introduction of 3D model implementation. For example, the 3D model did not replace the participants, in particular the presence of the initiator (the structural design crew that attempted to embed the structural design knowledge through the 3D model). Observations showed that the model neither influenced the duration (shortened/increased face-to-face interactions) nor changed the frequency of the meetings (as one would imagine if the meetings had been held less frequently). It can be argued that the model did provide 3D visualization and therefore the visualisations could carry a better understanding of the structural design knowledge. Therefore, face-to-face interaction would not be necessary. However, meetings were still held between these two crews, because not all actors in the design team could use the 3D model.

Furthermore, the 3D model did not change the actors' way of holding meetings. Beside the fact that actors engaged in discussions on 2D drawings (as explained § 5.3.1.1.), these meetings did not include access to the 3D model as it would support the actors' understanding towards possible design solutions/problems. In other words, there was no tool-support in the meetings where the boundary objects would be canvassed by the participants while they engaged in design dialogues. Using a 3D model stipulates the use of powerful computer systems to access and run the 3D model in the meetings. But besides the concerns about the need for a strong mobile system to access the 3D model, no device was available to support the model's outputs (3D PDFs). In the design meetings I observed and recorded, I found no evidence for using the potentials of the 3D model. Therefore, I can conclude that the 3D model used by the structural engineers did not play an additional role in the design team by designing and organizing the physical settings and formal face-to-face events.

B Design Workshops as Shared-Local Practices

In the fieldwork observations, I noted a practice emerging in the design team. This was a method of organizing a design meeting to run longer than regular meetings. This practice was called 'the design workshop'. These were settings that accommodated planned interactions, selected actors, and predefined artefacts that were relevant to the workshop content. Beyond the role of meeting, these workshops were emergent practices that attempted to enhance the interpretation of design objects and to promote social interactions and design dialogues.

The design workshops were organized to accommodate social interactions between the designers who worked in the same divisions. They were based on division of work in order to bring the actors together who were working on the same divisions, although in different disciplines.

The observations revealed that these workshops contained rotational social interactions. These were planned to target one division at a time and contained four time slots. In these time slots, the designers working in the same divisions came together and were expected to discuss the design issues that were related to the overlap of the different disciplinary design solutions between the design organizations. This promoted the development of social relationships between actors working in the same work divisions. Although it would seem logical to bring the actors who were responsible for the same sub-design together, these rotational interactions resulted in a limited overview and therefore a limited understanding of the overall design solutions. Within this 'work-division-shaped' physical setting, the interfaces between the different work divisions remained problematic. None of the actors (either the design coordinator or the attending parties) paid attention to a shared-slot where the interconnection of the divisions of work was achieved and where the actors focused specifically on the interfaces. In addition to this, the actors did not allocate a socialization slot, where the participant actors could possibly engage in both informal design dialogues and/or casual conversations that would enhance the empathy towards different work methodologies, agendas, and perspectives.

Figure 68 shows the agenda of a design meeting between three disciplines (HVAC, Architecture and Structural engineering crews). It illustrates that not all of the project leaders were continually present, even though the discussion point (offices) formed the design interest of the three disciplines. For example, in the 13.15 and 14.40 time slots none of the structural engineering crew (including the project leader) were recorded as being present. In the next slot, the three disciplines were brought together but with different participants of the disciplinary designers. Therefore, these meetings did not bring the designers who worked in the other sub-divisions together, even though the designers were expected to handle the interfaces.

Subject: CONCEPT[phase of design] Agenda of the meeting [date]	
12:00	General [the management meeting with disciplinary project leaders]
13:15	Offices [technical meeting between architecture and MEP engineering without structural engineering crew]
14:30	Terminal [technical meeting between structural engineers, architecture, MEP engineering with the participation of the project leaders and the designers responsible for this design division]
15:45	Housing [technical meeting between structural engineers, architecture, MEP engineering with the project leaders and the designers responsible for this design division]

Figure 68

Design meeting agenda illustrating the organization of the design meetings by reflecting the division of work in the design process

This option for sharing this empathy was only open to those designers who worked on the same division. This resulted in a different problem. These design workshops only accommodated the same representatives of the design crews whereas the rest of their crew worked in their organizational settings. The same individuals were involved in the interactions and conducting the co-design activities within their division. These designers discussed, negotiated, and applied the decisions taken on the design issues brought to the meetings. The design problems were solved intermittently. When additional issues had to be resolved, the designers interacted by using distant interaction techniques (i.e. e-mails, phone calls). The complexities of the decisions taken in the meetings were discussed and resolved through distant interaction mode. The designers who were involved in these workshops more chance of achieving a better understanding between the different disciplines due to the familiarity of the designers towards the approaches, mind-sets, and attitudes in the distant conversations. I was able to establish that no special attention was given to the distant interactions of the design team which hampered the support of the designers interpreting the exchanged boundary objects. The majority of the interpretations were done remotely in the disciplinary islands. Little attention was paid to this remote interpretation process, and therefore, to the designers who worked distantly.

The following quote demonstrates the influence of meetings in supporting the social relationships between the actors in the disciplinary and organizational islands.

"*...At a certain moment you have spoken to each other several times and then it becomes very easy to call someone. I think that is required; I think it is important that you go to the design meetings...* [A structural engineer working on the offices part] *made calculations but initially did not go to design meetings a lot. So for him it becomes more difficult to contact the architect. At the moment that you did that; not only by telephone but when you have also spoken to each other face-to-face, it becomes much easier to communicate with each other...*" (Chief Structural Engineer, 2010).

The images of the workshops in Figure 69 illustrate that these workshops were organized around the division of work and the designers working in the particular design divisions.

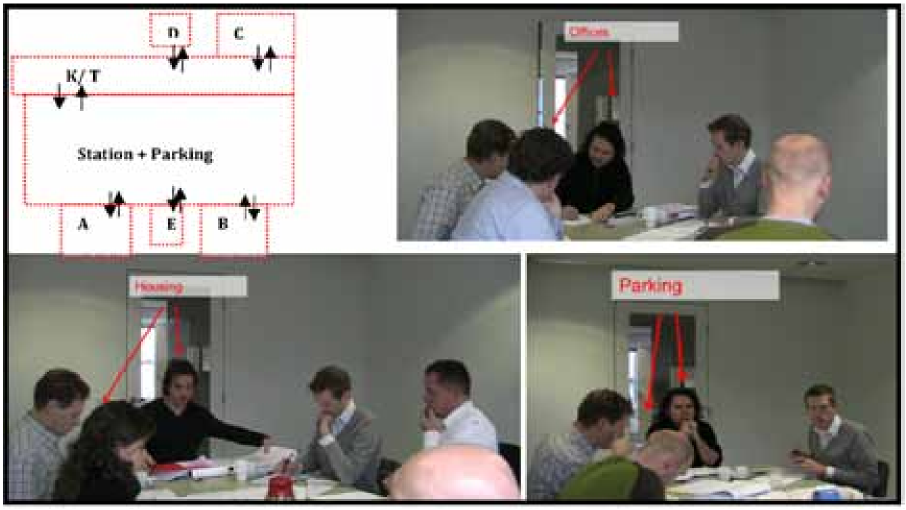


Figure 69

Images of an inter-disciplinary meeting showing the rotation of designers based on the division of the work in the project.

Data analysis revealed that design workshops did not provide sufficient social interactions amongst the design team members. Planning meetings based on the division of work resulted in fragmented design dialogues both within and between disciplines. In particular, the meetings (where design problems were resolved) did not have any special arrangements for inter-connecting the divisions and handling the interfaces between these divisions. The frequency was irregular, and therefore the actors' attendance was not continual and the individuals working in different divisions were not brought together (for interfaces). The continuum was necessary to enable the development of social relationships within the design team, as it serves a social infrastructure for sharing information and interpretation of the information. In addition to this, the design workshops resulted in co-design activities, but the outputs of the workshop did not allow the participants to proceed immediately. Often the lead architect was not present at such workshops as they were lengthy. The architectural crew had to wait for the final decision to be made by the lead architect. This absence created a delay (or waiting process) for the other parties, as they had to work with the final decision. To summarise, the design workshops were very intensive in terms of developing alternative design solutions, exchanging insights, and co-designing, and therefore these made knowledge sharing processes possible. Yet, these workshops still did not solve problems such as design changes and speeding the design process up. The intensive and all-day long design workshops also constrained the design process itself due to the absence of the lead architect and the absence of final design decisions.

§ 5.3.2 Conclusions

The analysis of the second case revealed two levels of insights. Firstly, it represented a bottom-up and emergent strategy that embraced digital technologies in dealing with the problems related to the limited knowledge sharing processes within the design team. The analysis showed that bottom-up emergent strategies can be difficult for the overall design team to embrace fully and that it is difficult to achieve commitment between the design team organizations. The analysis also revealed that the digital technology that the practitioners referred to as a BIM was not a real BIM implementation, thereby indicating that digital concepts are not still fully clear in practice. Particularly the design professionals and managers were not fully in line with the professionals who develop the tools to be used in the design practice. People give meaning to tools, the meaning between different professionals was not always well established when a new tool is introduced. The technical capability of a tool, the expectations of the designers from the tool and the competence level required to apply the tool to its full potential were not shared between all participants.

Secondly, this case showed that the digital implementation resulted in more constraints than expected. It required longer processing time to visualize the design solutions, which consequently resulted in delays in overall design team interaction. Reasons given for the problems behind the implementation are simple: no comprehensive study was available to evaluate whether digital technology was a solution, no in-depth estimation for the alterations that the technology would result in, and no deliberate operations were set up to align the technology to the current design practices.

With regards to being a KSS, the analysis showed that Case 2 had independent effects on each dimension. One main issue was regarding the use of tools, as no shared-tools were available to the actors and the potentials of the 3D model were not exploited in relation with the two insights stated above. Procedures were often implicit and did not specifically emphasize the actors' knowledge sharing mechanisms. Physical settings were undervalued and treated as a regular practice of actors. No attention was paid to organizing different events. The existence of efforts in each dimension of the Knowledge Diamond framework, together with the problems in Case 2, revealed that the actors did not have a framework in place to connect individual efforts for each dimension and to portray design and implementation as a holistic approach that synthesizes these efforts.

§ 5.4 Cross-Case Analysis

§ 5.4.1 Introduction

In this section, both cases are compared to identify commonalities and differences. The analysis has once again been based on the Knowledge Diamond framework. This cross-case analysis provides a basis for developing models for both the design and implementation of KSS for LCBPs. I look at the strategic aspects of KSS as well as the operational levels of the implementations carried out by the actors. I link together the implementations at both levels based on the KSS framework presented in Figure 16 (See § 2.5.)

At a strategic level, the main difference between the two cases was the type of KSS; Case 1 was a top-down intended strategy, and Case 2 was a bottom-up emergent strategy. Case 1 dealt with resolving inter-disciplinary problems and was managed by the overall design leader. Case 2 was a grassroots movement that started with one draughtsman. At an operational level, the main difference was their focus: Case 1 focused on physical-settings whereas Case 2 focused on tools.

Regardless of these differences, both strategies had limitations regarding promoting knowledge sharing processes within the design team. In Case 1, the actors designed and implemented the co-location and considered physical proximity to be sufficient. The actors did not evaluate co-location as a strategy that required designing and planning a long-term physical setting, along with the rules and tools required. Similarly in Case 2, the 3D model as a 'spin-off BIM' was not planned and implemented as a strategy, even though the actors deliberately tested the performance of the 3D model before they used it in the design process. In the end, both KSS were not used to their full potentials.

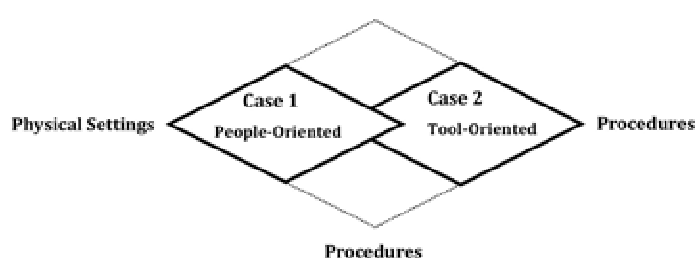


Figure 70
Discrepancies and similarities in terms of dimensions of the KSSs.

I will first analyse the differences and similarities at a strategic level, and afterwards I will discuss each of the four KSS components. The Figure 70 illustrates the cross-case analysis, as it will analyse the commonalities (illustrated by the two intersecting diamonds of each case) and the discrepancies between the KSS (illustrated by the dashed diamond lines).

§ 5.4.2 Intended and Implemented Knowledge Sharing Strategies

As noted in the introduction to this section, both cases represented two different approaches with respect to the type of KSS. Case 1 was an example of a top-down approach, whereas Case 2 represented a bottom-up approach. This difference influenced the way that the design teams realized their KSS. Case 1 represented how a design team missed KSS opportunities, even though there were detailed independent efforts and actions specified for each of the KSS dimensions. However, Case 1 did not embrace the behaviours of the different design organizations, it did not interconnect the dimensions, and it underestimated the full potentials of co-location as being more than a shared physical setting.

Case 2, revealed how a bottom-up innovation changed the existing design practice but failed to spread through the design team, so that it eventually became a mono-disciplinary effort. In LCBPs, bottom-up innovation of KSS is always complicated by the fact that it must also spread from one organization to the other. The 'bottom' must convince the 'top' in order to achieve this involvement of other organizations. Therefore, in LCBPs we can identify three different KSS routes: top-down, bottom-up, and lateral.

One of the discrepancies between the two cases was the level of commitment, besides their focuses (as one focused on tools and the other one was on physical settings). In Case 1 there was a high-level commitment between the design leaders, whereas in Case 2 there was a low-level of commitment among the design team members. This changing degree of commitment related to the contracts. Contractual agreements (both within design team organizations and the client team) revealed that contracts formed different legal infrastructures in which actors were either willing to be involved in shared-activities, or remained reluctant to not involve in each other's inter-organizational activities. Case 1 illustrates the willing attitude of the design team members to take part in their KSS. In particular, when the strategy was initiated by a company that sub-contracted the other design organizations, as seen in Case 1, the commitment level of the design organizations towards the main company became greater. In Case 2, the initiators of the tool-strategy were hierarchically equal to the actors who were expected to take part in the KSS. This equity (at least on paper) of the design team organizations resulted in an attitude whereby the initiating organization did not proactively convince the other parties to use the tool, and the other organizations were reluctant to use this new tool.

Both reasons resulted in an unshared new design methodology developed around tools. Commitment to the first strategy meant that actors physically took part in co-location, whereas non-commitment meant that one organization kept using a new tool and the others continued using their existing tools.

Another contrast between the two cases was in the degree that emergent approaches were valued and reframed to take part in the main strategy. Both cases contained emergent approaches. However, the way that these approaches were valued was different. The emergent approach in Case 1 was targeted at the KSS tool dimension, as the designer in the technical level had developed a software tool to 'freeze' and store design drawings. This software was aligned spontaneously to the design team's interaction and included the client team. In Case 2, the emergent approach was also targeted at the tool-dimension. The difference was that the emergent approach in Case 2 was proposed as an organizational strategy that attempted to alter the existing design methodology.

The contrast was mainly in the intentions, although both approaches were directed towards the same KSS dimension. The intentions behind the emergent strategy of both cases were to complete the 'missing components' of the overall strategy. The discussion therefore focused on the valuation of the emergent approaches and how to leverage these approaches to include a main strategy. On the one hand, the emergent tool in the first case was brought into official use. On the other hand, the way that the designers responded to the physical setting dimension (as the focus of KSS) was not considered. Feedback from the design team members (regarding the way they enacted KSS) was implicit as they modified the physical setting. However, these implicit responses against implementations were not 'visible' to the actors responsible for the strategy. In Case 1, the way that the co-location was enacted revealed implicit feedback that was 'visible' to me as participant observers in the co-located office. Firstly, the emergent software in which the official deliverables were saved, was embraced by the actors. However, the reactions of the design team towards the implementation of the overall co-location strategy was not evaluated or used to reformulate the co-location strategy.

The emergent tool in the second case was intended to be an overall strategy, which was to be adopted by all crews during their design processes. Yet, this intention was not preceded by any actions to convince the other crews regarding use of the new tool. One reason for this was that the structural engineering crew did not actually design a strategy. Nevertheless, they acted on a new tool that had emerged from the bottom-level (technical) and had been accepted by the top- level (managerial) based on results of the trial version of the tool (See § 5.2). Actors at both the top and bottom levels did not anticipate the new tool's advantages and disadvantages, and the changes that implementing the tool would have on the current design process. In addition, this tool-oriented strategy was introduced without the structural engineering crew having foreseen the need for planning activities, evaluation of its use and a reformulation of the overall strategy.

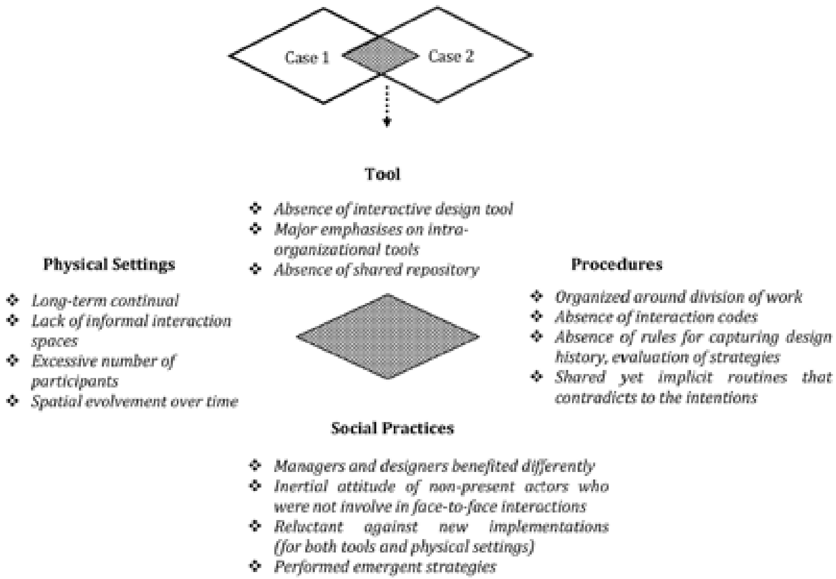


Figure 71

Illustration of the commonalities of both cases for their KSS in relation with the dimensions of KSS. The figure illustrates schematically that both KSS were not used with their full potentials. (More details can be found in the Table 8)

These two cases show that managers who ‘see’ potentials, set intentions, and identify implementations, may overlook the responses of their users at a technical level to these implementations. Another similarity was that in both cases, the actors missed the opportunity to use the existing tools that provided ‘ready visualisations’ in 3D, rather than having ‘the building in their heads’.

DISCREPANCIES		SIMILARITIES
CASE 1	CASE 2	
A. Physical Settings		
Long-term and continual physical setting	Ad hoc and short-term physical setting	*Actors organized the settings based division of work and shaped interactions*
Limited informal interaction spaces	No informal interaction spaces	*Used by and beneficial for managers*
Large number of people involved	Selective participants for formal interactions	*Major designing effort within disciplinary settings*
Limited common spaces (for interdisciplinary casual dialogues)	Attention on casual spaces (disciplinary-based)	*Did accommodate interactions yet did not guarantee knowledge sharing processes amongst actors*
Spatial evolvement over time	Structural evolvement over time	*Remained static against tool-implementations*
Co-design by managerial level actors	Co-design (by both technical and managerial level actors)	*Same individuals as participants for boundary crossing activities*
B. Tools		
Advanced representation techniques (due to change of software packages from the onset of the project to have a shared-software)	Remained insufficient to visualise ideas, externalize design solutions and provide design deliverables comparing to the 2D tools used by crews (i.e. in AutoCAD and Bentley MS, since the new tool was not pilot-tested)	*No awareness of both the extent of current reluctance of design crews regarding their own 'weapons' and the changes that any new tool resulted in design processes*
Facilitating simultaneous yet asynchronous disciplinary design (in relation with the unmanaged modification of requirements)	Hindered the basic need of the design crew; the simultaneous design process amongst crewmembers. (This need normally is a default nature of the design crews working separately based on their division of work (due to dependency on one individual)	*Major role of distant communication technologies for design team interactions*
No up-to-date tool (that 'visualized' the coherent design object in 3D)	Used as a clash-detector (due to the capability of visualized design object in3D)	*No shared repository from the onset of the project (each discipline had their own)*

>>>

DISCREPANCIES		SIMILARITIES
CASE 1	CASE 2	
C. Procedures		
Initial commitment to the tool-use (client driven) Implicitly formalized design team interaction (by the occurrences with client-team interactions)	No commitment to use of tools(at managerial level) No pre-planned formal interactions	*No rules for detecting/evaluating/ implementing emergent strategies explicitly (intuition-based)* *No rules for periodic assessment of implemented KSS*
Implicit interaction codes (imposed by the planning of physical settings)	Interaction codes imposed by division of work	*Explicit rules for exchange of design objects (when client team is involved)*
		Shared routines for informal interactions (followed implicitly)
		Irregularity of the attendees and occurrences of the meetings
		Sequences of meetings remained problematic (in capturing the design history)
		No rules to exchanging the discussions and decisions (between present/non-present parties in meetings)
		No rules for keeping track of the design process
		No explicit rule to interlink evolvement of scope and design object
		Strictly formalized client and design team interactions (managerial and governing level)

Table 8

Discrepancies and similarities between two cases regarding the components of their KSS

§ 5.4.2.1 Physical Settings

The long-term physical setting in Case 1 had the potential to promote social practices for sharing knowledge as it broke disciplinary and organizational boundaries through the physical proximity of participants. However, only the design leaders shared knowledge, as the technical level actors did not directly share knowledge, but had to rely on whatever knowledge their leaders chose to pass on to them. Managerial level actors exchanged their interpretation of the design information, and translated this to their crews.

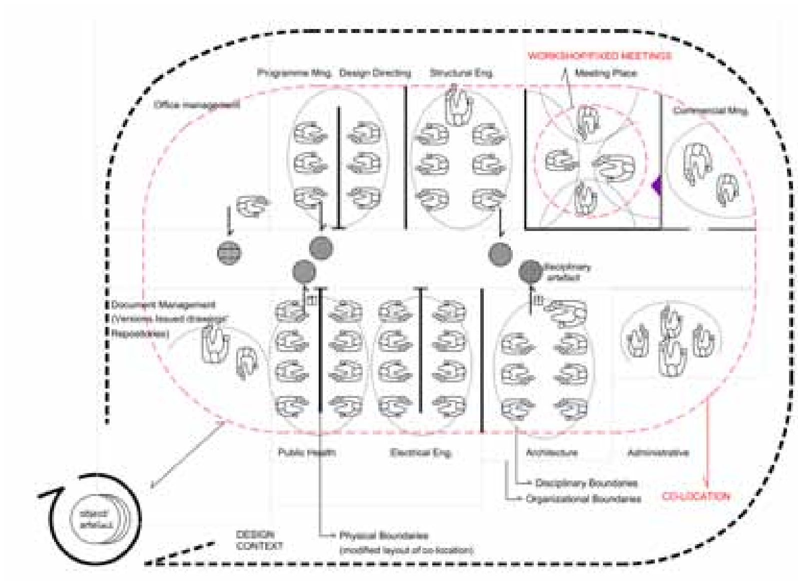


Figure 72
Co-location of domains and their division in the working space. (© Bektaş)

Figure 72 illustrates the reactions of social practices to the long-term physical setting. It reveals how actors responded to the physical space determined by the implementers, and how the space evolved over time due to gaps in the implementations (users modified their space to represent their organizational behaviours). The dotted ellipses show the boundaries of the disciplines, even though these had not been defined physically. The areas show the focused working islands, which were closed to the other disciplines. The black-circles (filled) illustrate the use of the informal interaction spaces in the co-location as these areas are detached from the focused-islands, and were mainly used for management level interactions. The closed-areas in the top-right corner were denoted as informal interaction areas and were used by the managerial level actors during inter-organizational discussions. These areas were organized on a short-term basis. Since managerial level actors used the three different settings, (long-term, short-term formal and ad hoc informal) they sustained the continuum of their interactions, thereby increasing the chances of successful knowledge sharing processes.

The implementers missed the connection between the different types of physical settings. Identifying these connections would have been a crucial factor in enabling the co-location as a KSS; however, this alone would not have been sufficient. In order to be a KSS, implementers have to define procedures that comprise the rules and norms for the use of physical settings and both plan and manage the occurrences of the settings.

Figure 73 illustrates the interactions leading to knowledge sharing processes among the participants in both Case 1 and Case 2 regarding meetings and workshops. It shows how individuals representing their parent organization provided artefacts in different design representations and interactions, which led to knowledge sharing processes within the same physical setting. In both cases, design leaders represented their knowledge domain and were in the 'front-line' as they had the potential for reciprocal knowledge sharing. Even though the design contexts of both projects were different, the mechanisms of meetings and workshops were similar; the designers who participated in these settings represented their own division. They intensively engaged in reciprocal interactions, however, these opportunities were only intermittent due to the schedule. In these settings, participants could observe the differences between their design methodologies, the production of artefacts and interaction styles, leading to knowledge sharing. Once the participants in these physical settings were aware of the setting's potential, they were able to understand each other. This understanding was based on the observation and reactions to discussions through interpreting the exchanged objects. Therefore, different styles of artefacts (Figure 73, Figure 74a and Figure 74b illustrated by hatched-circles) were available in the physical setting.

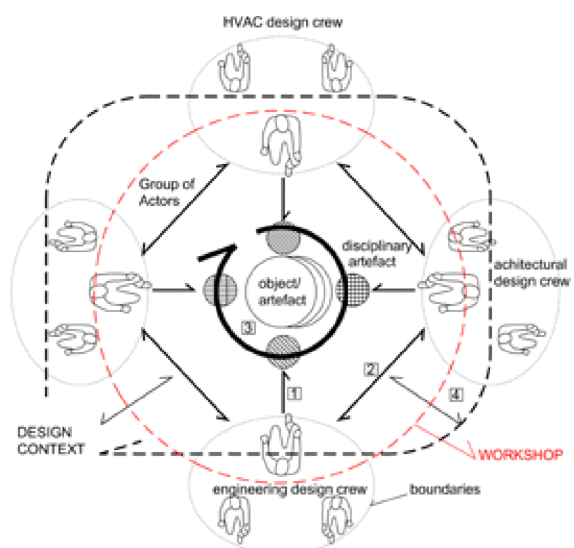


Figure 73
Meetings and design workshops as short-term physical settings in Case 2 (© Bektaş)

In both Cases, social interactions and observations were necessary to see and interpret the different modes of artefacts in order to gather the embedded knowledge. This required the presence of actors in the social process of knowledge sharing even though this process had been performed by other actors. In both Cases, the actors who benefited the most from the potential of the physical settings were the lead designers. In Case 2, the lead designers involved representatives of the work divisions in order to manage the design discussions in a more focused way. In both Cases, individuals who did not join any event which crossed their boundaries, and who did not engage in interactions, by only producing artefacts, had no opportunity to use the potential of the physical settings. These individuals were not involved in either the social or the observatory processes of knowledge sharing.

With regards to the exchange and processing of the design information, in both Cases actors exchange occurred mainly on an ad hoc basis and was interpreted directly within the physical setting. In Case 1, these processes took place in the co-location where the actors, who exchanged and interpreted design information, would potentially sit in the office space they shared. In Case 2, since exchanging and processing took place in meetings and workshops, formal and (when possible) informal conversations supported the knowledge of those actors who participated in meetings and workshops. They then became the agents who translated and transferred the dialogues and design solutions resulting from these settings. This enabled knowledge sharing from the agents (lead level designers) to the design team, even though the designers were present in the same physical settings.

Sharing knowledge through agents added an extra layer to the interpretation and translation of design information within the co-located design team. In this way Case 2 resembled Case 1. Even though there was no shared long-term physical setting in Case 2, the designers at the technical level were mostly dependent on their design leaders and their capacity to absorb, interpret, and translate design information in the project. The similarity between the Cases was that the majority of the design team members were absent from the physical settings where design leaders engaged in social conversations, brought in design problems, and manipulated design solutions.

Figure 74a illustrates Case 1 meetings where knowledge sharing was dependent on the design leader present per domain. Both cases shared the same difficulties regarding methods for collecting information about the design object, developing solutions, and confirming the meaning of the design objects within the physical setting as well as the issue of transferring this knowledge to the rest of the crew who was not present in the setting. Figure 74b illustrates the meetings in Case 2, where two knowledge domains physically came together in one physical setting. In this example, three individuals from each domain are present. One of them is the design leader, and the other two are representatives of different divisions of work. The lead designer is present throughout the meetings whereas the individuals are intermittently present (they come, present & discuss and go). In both settings, knowledge is potentially shared through the participants, and each individual has the chance to absorb, share and generate knowledge.

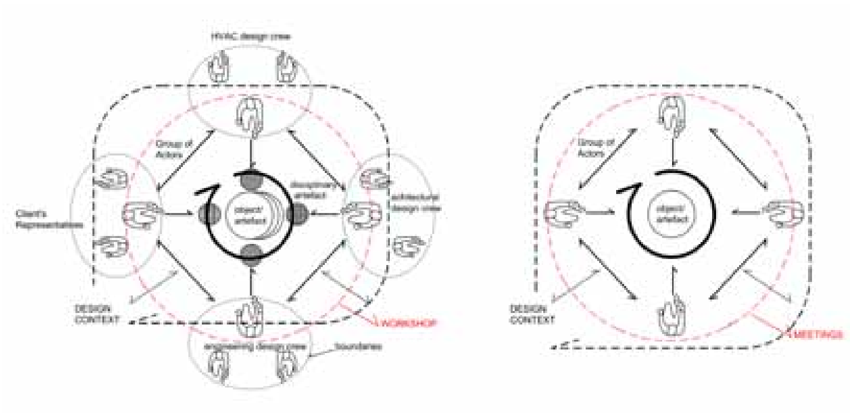


Figure 74
Figure 74a Case 1 short-term settings and Figure 74b Case 2 short term settings (© Bektaş)

Another similarity between the two Cases was their emphasis on the importance of disciplinary settings, rather than taking into account how multi-disciplinary physical settings should be planned to encourage knowledge sharing. Both Cases designed implementations organized around the division of work, rather than looking at the interfaces of these divisions, thereby strengthening the disciplinary boundaries. In both Cases, informal interaction areas were treated as settings that could be dismissed, eliminated, or left out of consideration. In Case 1, the informal interactions areas were replaced by focused disciplinary islands so that more space was available for the expanding design team. In Case 2, there was no arrangement for informal interactions in the meetings and workshops, except for a ten-minute lunch break. One can argue that the focused work islands were the settings where designers could concentrate on their work. Thus, design problems were solved in isolation there. However, by promoting focused work islands, this made the overall design object vulnerable to mismatches, particularly when interaction between designers decreased. Informal interaction areas have the potential to serve as 'glue' for social practices, giving those working in focused environments the opportunity to socialize in informal and shared environments. In both Cases, the major design process was performed within disciplinary islands, and they either lacked or had limited settings for informal interaction.

Both Cases showed that actors did not either perceive or use the potentials of physical settings. This shows that, even though technology-use is growing, there is still a need for face-to-face interaction. Considering the influence of technology on the design practices in both Cases, it would not be wrong to say that physical settings are still important either on a long-term or short-term basis. Both Cases revealed that physical settings were treated like individual events required for resolving design problems, rather than being perceived as a series of events leading actors to knowledge sharing processes.

§ 5.4.2.2 Procedures

Both cases were similar in terms of their lack of procedures for designing and implementing an intended strategy or evaluating the emergent approaches used to form an intended strategy. Case 1 had a static implementation route that remained limited to adjust emergent strategies. Case 2 was developed on an intuition basis but it lacked the commitment of other actors in the design team. Both cases were found to be similar, in the sense of having no rules for detecting, evaluating, and implementing emergent strategies. Besides, both cases did not include a periodic assessment of the selected strategies.

In both cases, implicit routines shaped the relationships within the design team, and the design team members shared them. Case 1 represented that the norms of the parent organizations shaped the way that actors enacted co-location. Actors reflected their varied cultures and values to their working settings, as they self-modified. Due to the missing procedures, it was observed that actors in the co-location office isolated themselves from the rest of the design team as a consequence of self-modification efforts. In this sense, the persuasive cultural norms resulted in thickening the existing boundaries within co-location. Case 2 did not portray a relevant complementary example for rules of physical setting.

Both cases revealed that if client representatives can be found 'in the picture' interactions were more formal, planned or at least explicitly determined. The common denominator in both cases was that there is an explicit route to plan and involve in client team interactions. Distant interaction procedures were either based on the correlation of official documents (i.e. project schedules, lists of responsibilities, organizational charts) or particularly dictated norms of project management bodies of the client teams (i.e. interaction norms that identify actors to be contacted, the content of design deliverables, the time dimension for sending/receiving/commenting the deliverables, and the types of interactions).

In both cases, contracts created a hierarchy that formalized interactions, and made capturing design decisions and the outputs explicit. This necessity was due to the legal responsibilities of organizations to each other. Therefore, actors in both cases attempted to capture the decisions/actions taken as proof of their fulfilments and responsibilities. Yet, each organization dealt with its own responsibilities independently, and did not treat that design as a multi-disciplinary and multi-organizational act. These independent efforts were not systematic, and therefore the projects had lacked design history that could contain sets of fulfilments and a continuity of decisions due to the high turnover rate of individuals and organizations as we identified in § 4.4. Thus, for managing these outputs of client and design team interactions, both cases remained problematic when keeping track of their design history, particularly regarding the change of design criteria by the client.

The content of the client and design team interactions (i.e. change of criteria and the reasoning behind the criteria changes) was not systematically recorded, although the outputs were prepared and digitally or physically restored. Both cases remained challenging in drawing a complete design history spread over decades. This history did not represent a complete history for the design team members who joined over time as well as the designers who had worked throughout the project's duration. Both cases shared a similarity in their formalized interaction between client representatives and the design history that had not been accumulated over time and became problematic for the design team (in spite of the formalized interactions and their outcomes).

Regarding the recording of decisions taken in design team meetings, Case 1 contained official reports for post- meetings on occasional basis. These reports were not always prepared for each meeting. In Case 2, recording decisions was based on individual notes and these notes were not cross-referenced between leaders. The design leaders themselves endangered that lead designers to false interpretation or incomplete information exchange.

§ 5.4.2.3 Tools

The difference in both cases regarding tool-dimension was the level of reluctance felt by the actors towards a new tool that needs to be aligned to their practices. When a tool is dictated by a client, the design team organizations implemented it without arguments. When a new tool was introduced at the start of a project, and that tool did not require a radical change or a new comprehensive learning to represent ideas and visualize design object, the tool was easily adapted by the actors. Even though a tool had different properties, it serves a function to be acquired and excelled, as actors learn how to use the new tool earlier in the project, when the design object was not very elaborated.

In Case 1, clients became a party ruling tool-use, even it was the case of using a software package in the design team. Thus, Case 1 represented an ideal step for tool-used practices, since using same software package eased communication and version problems. It set a virtual infrastructure in a simple manner. In Case 2, other crews and organizations did not embrace the tool. It represented a total contrast to Case 2. In Case 2, the design crew facilitated the tool sustaining the use of the tool throughout the design process, rather than the tool that facilitated them in easing their design process.

Both cases had a similar problem that the actors did not pay attention to the actual potentials or constraints of tools. Case 1 exemplified that sharing a software package amongst actors was enough for realizing a complex design object. Moreover, the actors failed to see how they could exploit the potential of the advanced KMS of the engineering company to a greater extent. This KMS would allow other organizations to access and contribute to storing their objects, finding other actors online, reflecting their ideas to current design progress (as contributing to the 'insights' segment of the KMS), a project-specific virtual KMS (as a part of the larger system) was not proposed. The current conventional design methods that design organizations used to handle the 'design object' predominated over the new tool-facilitated design process.

Another similarity was that in both cases, the actors missed the opportunity to use the existing tools that provided 'ready visualisations' in 3D, rather than having 'the building in their heads'.

§ 5.4.2.4 Moving from Existing Social Practices to Knowledge Sharing Practices

Up until now, I have examined the intended and realized effects of two KSSs and how the Physical Settings, Tools and Procedures have been implemented. While analyzing each of the selected aspects of KSSs ,it became clear which social practices had occurred in the design environment due to the implementations. Thus, the individual and cross-case analyzes illustrated how and to what extent the behaviours shared by individuals are performed by either mono or multi-disciplinarily interaction in regard to the aspects of KSS. In this section, existing social practices have been described in order to depict the conditions of knowledge sharing practices. This has been achieved by making explicit use of the tools, procedures, and physical settings.

The two cases revealed different forms of social practices. Regardless of the type of KSS (whether people or tool oriented), social practices engage in both active and passive mechanisms of knowledge sharing. The focus aspect of a KSS does not always determine how the social practices are carried out. Case 1 represented an example that showed how, in a long-term physical setting, tool-supported interactions might occur and dominate the way that social practices engage in knowledge sharing practices. Case 2 represented the opposite: a tool-supported design process cannot be separated from the potential of physical settings, because physical settings accommodate the active involvement of designers to design dialogues, co-design process and interpret design information. Both cases represented how current social practices comprise both active and passive ways of knowledge sharing. However, both cases also revealed that the focus aspect of a KSS can make the other aspects appear to be less important from the implementers' perspective. In order to prevent this, it is important that the existing social practices are stipulated. This stipulation can be used to illustrate how social practices can become knowledge sharing practices in LCBPs as depicted in Figure 75.

The empirical analysis of the two case studies resulted in four important variables of social practices for knowledge sharing practices which are as follows: 1) distant and/or in-house (or within same physical setting), 2) synchronous and/or asynchronous, 3) working on same and/or different tasks and 4) interacted directly and/or indirectly. These four variables # are related differently to each aspect of a KSS. This influences the way in which social practices result in knowledge sharing in LCBPs. These various knowledge sharing practices have been exemplified below and are based on the four variables mentioned above which lead to different modes of interaction in the design environment.

The first type [numbered as 1 in the Figure 75] emphasizes that social practices occur within distant work areas. It occurs within the distant physical settings, since these settings represent focused working areas in which actors perform the majority of their design tasks. Within focused areas, actors (individuals) individually gather the meanings of information exchanged and they generate knowledge embedded in the artefacts. They generate and externalize their knowledge through the interpretation of artefacts. Therefore, this type involves passive knowledge sharing, as the interpretation of design information is rendered without socialization mechanisms. This type is done individually, regardless of what someone's role and responsibility is during the design process. This entails designers who work on their drawings, civil engineers who work on their structural designs and calculations, etc. Although these types of social practices vastly occur on an individual level, it requires multi-disciplinary involvement in order to gather the intended meaning from the design deliverables exchanged by other actors.

Once the intended meaning has been conveyed and the social practices result in a passive and indirect way of sharing knowledge, the disciplinary artefact can be prepared. However, these practices become vulnerable to misinterpretation, since actors do not engage in dialogues or social interactions. This type is asynchronous and individuals might even work on the same task or on different tasks without notifying each other. Asynchronous and focused design tasks enable individuals to concentrate on the meaning of the objects and they can apply these insights to their disciplinary artefacts. This interaction via objects is a distant mode of knowledge sharing, and therefore there is no direct interaction between individuals. Nevertheless, this mode of interaction is frequently neglected due to the emphasis placed on collaborative and shared design environments. This study revealed that remote interaction is crucial in the context of design, particularly when actors are equipped with tools. Social practices can result in knowledge sharing practices, when interactions lead designers to reciprocal dialogues through the facilitation of tools. This, in turn, leads us to the computer or tool-mediated social practices.

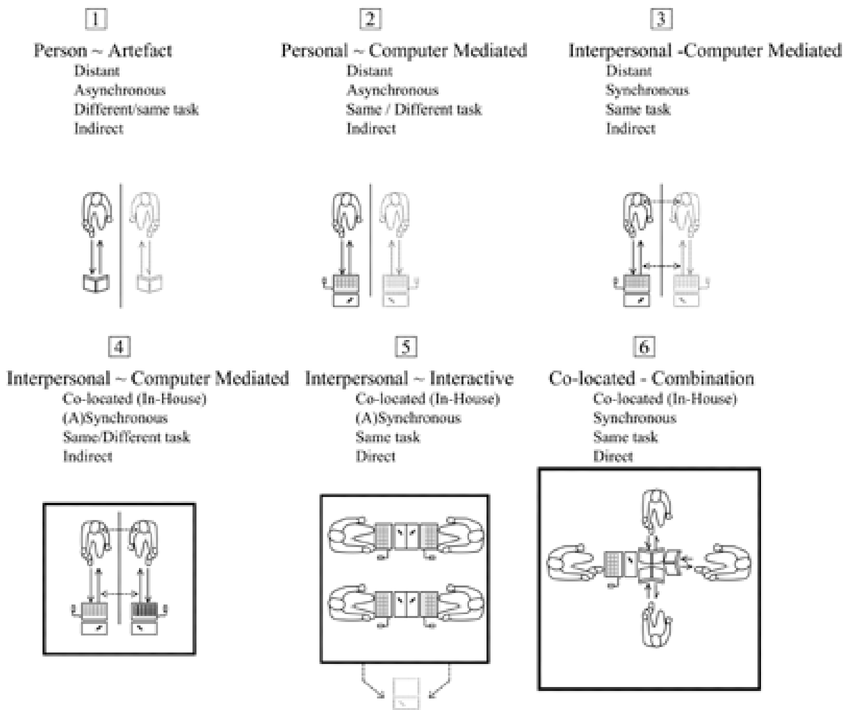


Figure 75
Examples of social practices based on the four variables as identified [1~6]

As illustrated in the Figure 75 as Type [2], tools create a 'channel' that can be used by actors so that design information can be exchanged, or so that actors can engage in design dialogues and social practices will help them to become equipped for knowledge sharing. These types of social practices involve actors who acquire knowledge through reading and interpreting and who apply it immediately to their work. The same properties of the interaction as in Type 1 apply to this type. Individuals do not interact directly but through exchanged design objects. The 'power' of computers enables individuals to view the different layers and search for possible clashes. Knowledge sharing is facilitated through computers since exact overlapping (in scale) can be done. The immediate update and modification of the design objects are thus enabled. Social practices produce rules for keeping the tool-mediated interactions tracked, particularly between different design organizations. However, these rules are ad hoc and organization-specific rather than project-specific and they are shared explicitly among different design organizations.

The third example of social practices refers to people working in distributed settings and who interact simultaneously or asynchronously with each other as part of their design work. This is an example where social practices comprise computer-mediated interaction amongst individuals [3]. Social practices are performed by direct, but distant interaction among the individuals. Knowledge sharing practices can be achieved through overlapped and confirmed design solutions and by design dialogues provided by in-direct communication mechanisms such as phone calls, e-mails or a software i.e. Skype. Depending on the frequency of the communication, regulating the computer-mediated interactions becomes difficult and capturing the changing decisions remains problematic.

The fourth example of social practices is one in which actors engage in the same physical settings as illustrated in [4]. This mode is computer-mediated interaction within a shared-physical setting. Individuals share the same physical setting and make use of the advantages of computer technologies such as accessing the project materials, e-mails, or collaborative sketching, etc. This represents a typical disciplinary or multi-disciplinary office environment. Designers are positioned in such a way that they can perform their tasks, yet there are physical boundaries, which separate the disciplinary division. The interaction among the actors is still performed by indirect communication mechanisms such as phone calls, e-mails, and/or direct interaction as informal and formal conversations. For informal design conversations, designers need to cross their boundaries. In co-located design teams or design crews, this type of social practice occurs, but it does not guarantee knowledge sharing. Physical proximity does not facilitate knowledge sharing practices, as it can result in preserved boundaries when implementations do not encourage actors to overcome the barriers and they do not regulate the practices of actors.

The fifth example of social practices is the co-located (in-house) & synchronous interactions of actors [5]. Actors are present in a computer-mediated physical setting. These types of practices are performed through shared-computer-mediated interaction within the same physical settings. This represents a reflective interaction mediated by both a computer and interactive setting. Computers facilitate co-designing between actors such as overlapping, modifying, and producing design objects while design dialogues occur. Actors are capable of explicitly capturing design issues, decisions, and discussions and defining subsequent action. This mode of social practices is more visible due to the prompt responses, and prepared objects that embed the knowledge shared within the physical setting. While tools support actors by facilitating distant interactions that lead their externalization processes of knowledge, a shared-physical setting can enable actors to observe each other's responses and reactions.

The sixth example is another form that combines computer-mediated interaction with a physically shared environment such as illustrated in [6]. The difference from the previous type is that this mode requires shared/synchronized software in which designers work synchronously and reflect on each other's work progress simultaneously. This mode also contains co-design activity that is also visible to the actors who are not present in the physical setting. Therefore, this mode allows distant and interactive work areas to be connected through the mediation of the tools. This mode enables actors to perform both passively and actively when sharing knowledge. Both cases revealed examples of [5] and [6] mode of social practices such as design review workshops. Although both social practices encompass all of the necessary ingredients used in knowledge sharing (see Chapter 2), there are nevertheless shortcomings. Firstly, due to the intensity of participation of actors, it is not realistic that one can expect this mode to be maintained, as is the design process is long and continuous. Secondly, the planning of participants, managing, and capturing knowledge shared by actors are challenging issues.

As illustrated, social practices include different motive modes of actors that conduct their design activities within focused, interactive, virtual, and physical spaces. Different social practices are exemplified and illustrated, based on the result of the case analyses. The examples provided above attempt to clarify different types of social practices that exist in LCBPs. Depending on the project specifications and the different motives of actors (analyzed in § 4.3, § 4.4 and § 4.5), different modes of social practices can dominate the design process. Each type of social practice can be found in LCBPs as 'particles' of knowledge sharing practices. However, these particles are either not valued as a part of the shared practice of actors or they are too disparate to deal with the problems that occur as a result of limited knowledge sharing. Thus, it becomes necessary to develop an integral and holistic approach that deals with interconnected implementations that are targeted at each aspect of knowledge sharing and that encompass the commitment of designers and managers towards a project-specific KSS.

§ 5.5 Conclusions for Current Knowledge Sharing Strategies

This chapter reported the empirical data analysis in relation to the second research question. It addressed the current KSS for LCBPs by investigating the two case studies through the Knowledge Diamond Framework. The investigation has led to the following conclusions. There are two levels of conclusions, strategic and operational.

For the conclusions on intended and implemented strategy, the holistic framework is used as this framework embeds the nature of a KSS (i.e. intended, emergent), whether it was top-down or bottom-up, the degree to which the intended KSS had been realized, and how each strategy was enacted and resulted in a KSE .

For the operational level, the Knowledge Diamond framework is used to structure the conclusions, as the Knowledge Diamond has been illustrated to discuss the content of each KSS in both cases. The conclusions have been drawn based on the four aspects of the Knowledge Diamond (Physical Settings, Tools, Procedures, and Social Practices).

§ 5.5.1 Conclusions for Intended and Emergent Knowledge Sharing Strategies

The conclusions concern the implementation levels (bottom-up/top-down), and the types of strategies (intended/deliberate/emergent/ (un)realized). Using a top-down strategy ran the risk of failing or being less effective, unless the implementers embraced the designers' needs and the emergent strategies that are often the results of the needs, if these needs are not taken into a consideration. In the case of bottom-up strategies, the risk of failing was associated with a lack of management commitment (particularly in the one case where the design team had the tendency to keep up the technological solutions and embed them into its design practice).

The deliberate strategies that we identified had not been customized to the projects. There was no common ground regarding how specific a strategy would need to be. The deliberate strategies neither were built upon an in-depth understanding of the characteristics of the LCBP, nor were they built on the objective of the strategy. The intended strategies that dealt with knowledge sharing problems often lacked a clear and shared vision that synthesized the expectations, investments, and contributions of the actors. When this vision was lacking, the parties were challenged to draw a clear implementation path that might assist the implementers as well as the designers who had to enact the strategy and who were anxious not to derail the project. When a shared vision was missing, the actors failed to establish commitment towards a long-term strategy. Therefore, we conclude that when a shared vision and commitment among different groups of actors is missing, strategies are likely to end up unrealized.

Even in cases where the parties attempt to develop a shared vision for an intended strategy, the implementations and activities are often displaced from this shared vision to become a deliberate strategy. The feedback loop that would be required to create a connection between the shared vision and how people enact the strategy was often missing. In this case, the evolving (and mismatching) relationship between the vision of a strategy and the real implementation resembles the relationship between a project brief and the design throughout projects.

The role distribution within the project teams about how a strategy is planned and enacted was often ambiguous or otherwise done on ad hoc basis. The ambiguity that can be observed in this management role and act carries the risk that the strategy is vastly unrealized, as no explicit responsibilities and steering roles are set. In the end, either a deliberate strategy becomes a single individual's responsibility or no party will accept the responsibility.

The deliberate strategies identified in this study that dealt with knowledge sharing problems were often initiated by one organization, typically the one that held the main responsibility and more disciplines working on the project. This party was not necessarily the one that would dominate the design environment and influence all the other parties about the way that the design was undertaken. Example to the 'dominant organizations can be given as signature designers, star architects, or the so-called 'prima donna architects'. The party who initiated a strategy was often the organization that had more domains to be integrated, and who was dependent on the knowledge of other organizations, and therefore had more to lose in the case of knowledge sharing problems. The risk associated with these deliberate strategies that were initiated by one single organization was the low level of recognition and acceptance by the others. In the end, this type of strategy loses (or never acquires) the intended participation of other organizations involved. In best case, it becomes beneficial solely for the organization that initiated the strategy.

The emergent strategies in this study did not always receive uniform recognition throughout project team. They formed pockets of practices that tackled the same problem and therefore, emergent strategies remained often limited to specific disciplines and not even very visible within one project organization. Although the emergent strategies had a greater potential to promote knowledge sharing across disciplines, they also ran the risk of remaining limited to one group of practitioners. Therefore, these local efforts resulted in often task or discipline specific CoP, but they did not reach out to the managers and were certainly not recognized as being an inter-organizational strategy. This illustrates that there was not only a broken link between the managers and the designers (operational level), but that there was also a disconnection between the disciplines who worked on the same project and their parent organization, which included different disciplines. This also illustrates an insufficient intensity in the dialogue between the departments (among managers and their designers and across designers in different disciplines), as each department became a sub-organization within their parent organization.

Emergent strategies also had the tendency to focus on one aspect at a time (as illustrated in Figure 76). When a strategy focused solely on a single KSS dimension, there was always the danger that the strategy would fail. Such strategies could only achieve what was intended based on that single dimension, but they were unable to fulfil the complete requirements of a KSS.

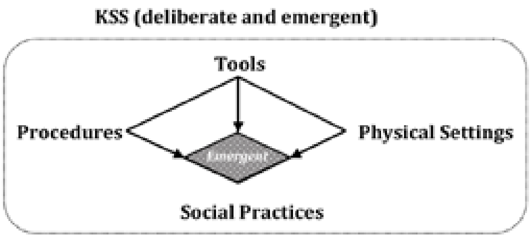


Figure 76
Emergent strategies in relation to deliberate (and consequently intended strategies)

This leads us to the final high-level conclusion. When a strategy targeted each dimension separately, or when there were local practices that addressed each dimension of the KSS independently, such a strategy could not achieve its full potential in LCBPs. We found that emergent strategies may arise in any dimension, but they do not create a coherent overall strategy by themselves. In order to achieve the full potential, emergent local practices need to be related to and in dialogue with the intended strategies.

§ 5.5.2 Conclusion for the 'Knowledge Diamond' Framework

In this study, practitioners did not have lucid approaches for designing and implementing project-specific KSS. However, LCBPs do contain emergent or intended strategies mostly dealing with knowledge sharing as they are either top-down or bottom-up. These strategies deal with one dimension at a time and they do not have an inter-relationship with each other as illustrated in Figure 77.

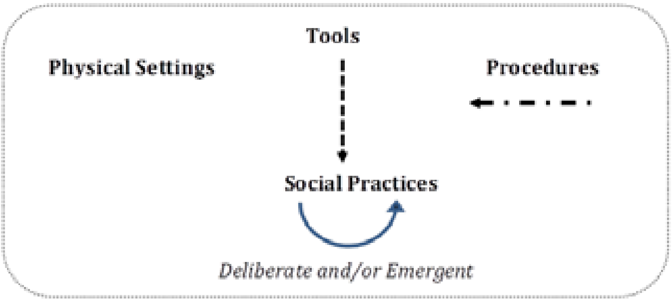


Figure 77
Current practices regarding the four dimensions of the Knowledge Diamond

The Figure 77 exemplifies that in each LCBP, there are local practices dealing with problems related with the aspects of the Knowledge Diamond. As seen in the figure, those practices are independently held often by one organization. When a local practice is performed at an inter-organizational and/or multi-disciplinary level, these practices have a danger to be disconnected from the rest of the design team. In both cases, the local practices perform activities that fulfil the intentions for designing and implementing a deliberate KSS, but often these activities are not planned prior to the design process and in the end, they deal with knowledge sharing partially. The dotted lines among the aspects of the Knowledge Diamond represent these independent and partial activities in LCBPs. Below, the conclusions are elaborated.

This research revealed that current practices in LCBPs have the tendency to focus on one dimension for dealing with knowledge sharing problems such as BIM/3D models as tools and co-location office as long-term physical setting. Assuming that a focus on one dimension might cure all of the problems was not sufficient to promote knowledge sharing. Actors in LCBPs missed an overarching strategic framework that enabled them to organize, plan and detail these individual efforts and activities of actors so that knowledge sharing problems could be addressed and that knowledge sharing processes among actors could be promoted. Below, the way that current practices dealt with the challenges of LCBPs is summarised.

1. Providing physical settings creates proximity, but it does not guarantee knowledge sharing.
2. Tools cannot facilitate the interaction or shared design activity, unless social practices also embrace the tool use and create awareness of the capabilities and limitations of the tools.
3. Procedures do not provide sufficient detail and there was not sufficient commitment to implement them.
4. Social practices were not shared by all members of the design and client teams. Where knowledge sharing did take place, it did so in a spontaneous manner between several members of the team. Current social practices were not deliberately directed at the commitment to share their knowledge, interact and exchange design information while being aware of which boundaries should be crossed, and which boundaries should be left intact.

Below, these conclusions have been elaborated.

§ 5.5.2.1 Physical Settings

Providing physical settings does not promise occurrences of knowledge sharing.

This study revealed that current design practices either intentionally or spontaneously use the opportunities of organizing physical settings in dealing with the challenges of LCBPs. Designers or managers perform these intentional or spontaneous efforts, even though there are tools that facilitate actors. Thus, tool implementations do not make physical settings obsolete.

- Physical settings in LCBPs are organized as long-term and short-term basis in order to avoid communication breakdowns, stimulate interactions, and share and process information reciprocally. Although current practices often are aware of these potentials intuitively, they do not perform deliberate design and planning implementations to exploit the potentials of physical settings in facilitating knowledge sharing practices.
- Design team organizations do not pay attention to design their interaction spaces throughout LCBPs. The physical settings that accommodate the interactions of actors (in both their organizational islands and multi-disciplinary interaction areas) evolve over time. However, this evolution of the physical settings often adds more boundaries to sharpen the territories of actors, and therefore there is the danger that this will hinder the interactions of actors.
- Similar to the interaction spaces, current design team organizations do not manage explicitly the team growth of LCBPs over the course of time. The team growth is reflected in the layout of the working spaces of the design team, which is on an ad hoc basis so that they are not planned systematically in order to boost the interaction of actors and to integrate of the design solutions. As a result, both focused and shared workspaces reflect the organizational crowd and therefore remain limited in benefiting the potentials of physical settings for knowledge sharing.
- In LCBPs, the decisions taken in physical settings are in danger of disappearing, unless the actors do not deliberately capture and record these decisions along with their reasoning there are different managerial physical settings are organized. There are differently conducted physical settings with different representatives of client and design team organizations. The decisions and actions taken in one level and in one physical setting are challenged to pass to the other level. This is not only a problem that occurs at inter-organizational level, but also within the organization such as among design crew members, design leaders, project managers etc.
- Physical Settings did not benefit all of the actors in LCBPs. The number of design team actors was large and therefore, there were always certain actors 'on the front line' of interactions among other disciplines and organizations. Thus, not every actor was given a chance to benefit from the potentials of physical settings and to perform his or her design activity by 'via-via' dialogues and interpreting information. As a result,

the majority of design teams did not benefit from physical settings. It unrealistic to expect that each actor in LCBPs would benefit from the chance of observation, imitation of 'others' practices', interactive co-design possibilities and have the same level of project understanding.

- There is an inequity between the design crews represented by design team organizations in LCBPs. This inequity is often disregarded in order to plan the physical settings and occurrences of interactions in LCBPs.

§ 5.5.2.2 Tools

Tools cannot facilitate either interaction or shared-design activities among actors automatically, unless social practices embrace their usage and that there is an awareness of both capabilities and capacities of tools in the design process.

This study revealed that in current practices varying tools were used that were not shared by all actors. Actors were not fully aware of the potentials and constraints of their current tools as well as the new technologies such as BIM, 3D/4D models, etc.

- Current practices tended to treat new technologies as sufficient for dealing with the challenges of LCBPs. Actors failed to see the necessity to align their design practices with these new technologies.
- Current practices in LCBPs have attempted to keep up with the developments in technology and to use the new technologies in their design processes (such as BIM, 3D models). However, they had the tendency to treat such technologies as panacea. New tools require experience, which must be acquired first so that the exact results of a design representation can be anticipated and so that they can be used as efficiently as the tools used before.
- Existing tools were the 'weapons' of actors in order to externalize their knowledge and to realize their design tasks within the anticipated time, and actors were reluctant to learn new tools or to work on a shared software package that required new rules and defined new methods that take time to learn.
- In LCBPs, local practices emerged to deal with the challenges of LCBPs spontaneously, when there is a mismatch that frustrates the designers yet are not recognized by the managers. These local practices involved introducing existing tools within a wider context (such as the 3D model in Case 2) or developing a software program in order to deal with these mismatch in the design team.
- This research showed the efforts required in terms of organizational development in relation to tools that had been initiated in order to deal with inter-organizational problems.

§ 5.5.2.3 Procedures

There is a lack of ground rules for actors in design teams in regard to how their knowledge sharing processes should be regulated.

This study has identified how procedures can become the missing explicit bond between design team organizations so that actors might commit to and enact implementations that have been planned throughout the project duration. This study has emphasized that there should be ground rules that define, clarify, and regulate the knowledge sharing processes of actors in LCBPs.

- In LCBPs, we found a plethora of conflicting procedures, which fail to draw clear rules that regulate interactions, design information exchange and planning (and designing) physical settings.
- Explicit procedures that particularly target at the mechanisms of knowledge sharing were limited with client interactions.
- While there were some rules for how actors should share knowledge in LCBPs, these were either implicitly shared or dispersed. Design teams implicitly and/or intuitively conducted their behaviour towards inter-organizational knowledge sharing mechanisms. These behaviours were often not pre-determined beforehand; they evolved as time passes. The problem is not their intuitive or implicit nature but rather that these shared rules may result in isolated social practices that solely correspond to the agenda of one organization and contribute little to sharing knowledge. If the rules are implicit, managing the knowledge sharing of actors becomes difficult.
- The extent of explicit rules differed between organizations. This was problematic as actors focused on their own organizational procedures, and did not pay attention to setting up joint rules from the onset of the project.
- Client and design team interactions were regulated by documents, such as project schedules, planning, interaction or submission formats that the client teams of LCBPs request.
- The outcomes of physical settings and/or inter-organizational interactions attempted to be recorded by the participants independently but not systematically. Based on individual and non-systematic records, the design team organizations become limited in capturing decisions or changes in design solutions. Thus, LCBPs lacked a shared project history that could have been built through negotiating the design philosophy and the scope of the client with the stakeholders.

§ 5.5.2.4 Social Practices

Social practices are enacted by a group of actors who participate in knowledge sharing processes, but who do not comprise all of the members involved in the design and client team. The degree of social practices performing knowledge sharing practices is not sufficient enough to form a project culture that establishes a ground for people to share knowledge at the inter-organizational level.

This study revealed that LCBPs accommodate practitioners at different levels who engage in knowledge sharing processes, intuitively or intentionally. Social practices comprised social entities that grow and benefit from sharing their knowledge, due to their personal experiences that proved to be present in physical settings or that made use of the technological support during their design processes and interactions that all leverage their understanding and enhance their mental capacities to solve design problems. The current social practices form project-specific 'sub-cultures' that encompass activities of participants for knowledge sharing. However, this sub-culture does not represent sufficient group of people to tackle problems encountered by limited knowledge sharing.

- Although we identified intended strategies that dealt with at least one dimension of a KSS, social practices often did not succeed in enabling knowledge sharing processes throughout the design processes.
- Currently, social practices found to be dispersed and only shared to a limited extent. The extent of sharing was influenced by managers' openness to conducting shared activities and their commitment towards other design team organizations.
- Current practices helped to bridge the distance between actors through interacting electronically via e-mails etc. The physical distance and time lag between interactions gave actors time and space to elaborate the design issues that had been exchanged via e-mails.

This study revealed that current practices of knowledge sharing do not always succeed. In order to design and implement intended KSS for LCBPs, it becomes important to know the way in which social practices address knowledge sharing. In any kind of approach, intended or emergent, the mechanisms of knowledge sharing need to be understood in relation to the implementations and the effects of implemented/existing tools, physical settings, and rules used by the people in the design process. This study focuses on the different aspects of knowledge sharing and the different levels of implementations that enable stipulation to elaborate what the existing social practices are and how they have the potential to promote knowledge sharing practices. This stipulation, drawn by the results, will provide a basis for further implementations for practice.

6 Discussion, Recommendations and Reflection

§ 6.1 Introduction

This chapter provides a critical discussion of the research results and the implications for designing and implementing project-specific Knowledge Sharing Strategies (KSS) for Large Complex Building Projects (LCBPs). The chapter first revisits the main research questions posed in Chapter 2 and summarises the main findings from Chapters 4 and 5. Secondly, this chapter reports on the confirmation of the results obtained through discussions with the expert panel. As an answer to the third research question, this chapter provides the practical implications and proposes a template for designing and implementing a project-specific KSS for LCBPs. The chapter concludes with suggestions for further research.

§ 6.2 Main Insights in terms of the Research Questions

Up until now, the results of the two cases have been reported in Chapter 4 in terms of the characteristics of Large Complex Building Projects (LCBPs) and in Chapter 5 in terms of the current Knowledge Sharing Strategies (KSS) for LCBPs. The results obtained in answer to the first main research question showed that the main characteristics of LCBPs, namely uniqueness, temporariness and complexity, became the main challenges for knowledge sharing in LCBPs. The results obtained regarding the second main research question showed that both approaches selected for knowledge sharing remained problematic in fulfilling the intentions of actors. We also found individual efforts on each dimension of the Knowledge Diamond Framework in both cases, but these efforts were not linked to an overall strategy. Below, the first two research questions are revisited and the essence of the results is presented in Table 9 and Table 10.

Main Insights for Research Question 1: Real Challenges of Knowledge Sharing Strategies	
Uniqueness	Uniqueness is sometimes perceived as an impediment in knowledge sharing. Yet, whereas projects are per definition unique, many of the aspects regarding how they are approached and managed are actually generic.
Temporariness	LCBPs are temporary, but in fact, they often last several years or decades. If you regard decades as being temporary, then this is a mind-set that will hinder any strategy from developing and which is meant to target inter-organizational knowledge sharing.
Complexity	In LCBPs, complexity as such is not the main problem, but fluidity and interrelations between sub-systems do pose problems. Large, complex projects are commonly decomposed into parts in order to make them manageable. Each part becomes a project within a project and develops its own design criteria. A knowledge sharing strategy needs to take this division of labour into account and it should provide instruments for supporting coherence among sub-tasks and sub-systems.

Table 9
The three main insights provided in Chapter 4.

The first research question was, “What are the typical characteristics of Large Complex Building Projects (LCBPs) and in what way do these present challenges for knowledge sharing?” When analyzing the data, I examined the three characteristics of LCBPs that are generally discussed in the literature: uniqueness, temporariness, and complexity. However, the real barriers to designing and implementing deliberate KSS for LCBPs appeared to be the current perceptions that actors have towards these characteristics. The way that these three characteristics present challenges for knowledge sharing has been summarized above in Table 9.

The second research question was, “How are the challenges of large complex building projects currently being addressed and are there certain knowledge sharing strategies for large complex building projects that can be identified?”. This study revealed that knowledge sharing strategies can be identified, but they still remain implicit in the design processes. I also found that explicit strategies cannot be applied universally to every project. The comprehensive analysis was at two levels; 1) the strategic level accommodating emergent and intended efforts and a suitable framework synthesized by both the Activity Theory and the aspects emerged in the literature review, and 2) the operational level containing efforts on each four dimension of the Knowledge Diamond. Based on the answers, the main insights have been drawn and are shown in the Table 10 below.

Main Insights for Research Question 2: The Current Knowledge Sharing Strategies	
A.Existing Deliberate and Emergent Knowledge Sharing Strategies	
Deliberate	A top-down deliberate strategy may fail or be less effective if the implementers do not embrace the designers' needs as well as emergent strategies.
Deliberate	A bottom-up deliberate strategy tends to focus on only one dimension at one project for dealing with knowledge sharing problems. The commitment of top-level managers is needed in order to integrate bottom-up efforts into the overall strategy, and to persuade other project partners to create commitment and participation among their members so that the KSS can be enacted as a shared effort across all organisations involved.
Deliberate	Efforts were often disparate; there was no clear, shared vision behind the deliberate strategies that connected all actors that are expected to contribute and enact KSS.
Deliberate	In cases where a strategy was based on a shared vision, the implementation could still deviate from the original intentions, due to the changing conditions or interests of the participating parties. Thus, the way that the strategies are implemented does not necessarily correspond to the shared vision, since the vision has not been explicitly revised.
Deliberate	Managers play a crucial role in monitoring activities and steering the organizations in the implementation of the shared vision. However, we found that this role was not recognized by the parties, and that it was carried out on a ad hoc basis.
Deliberate	The current deliberate strategies were often initiated by one organization that had more responsibility and more disciplines working on the project and therefore more to lose.
Deliberate	Current deliberate strategies were not customized to the projects. There was no common ground with respect to the scope of the project and which strategy would be needed for a given project. Deliberate strategies were not built upon an in-depth understanding of the characteristics of LCBPs.
Emergent	Although emergent strategies had a higher potential to promote knowledge sharing across disciplines, they ran the risk of remaining limited to the same group of practitioners. Emergent strategies did not always gain recognition, even by those within the same organization.
Emergent	Emergent strategies had the tendency to focus on one aspect at a time. When a strategy focuses solely on a single KSS dimension, there is always the risk that it will fail or not achieve its full potential. Such strategies could only achieve what was intended based on that single dimension, but they were unable to fulfil the complete requirements of a KSS.

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Main Insights for Research Question 2: The Current Knowledge Sharing Strategies	
B.Enacted Strategies in terms of the Knowledge Diamond Model	
Physical Settings	Introducing a tool-oriented KSS did not make face-to-face interaction obsolete. Long-term physical proximity did not guarantee knowledge sharing. The same physical settings could be enacted differently and produce different beneficial or adverse effects for different actors. While co-location supported informal interaction, it also carried the danger that decisions were taken informally and their rationale forgotten, unless the decisions were recorded systematically.
Tools	The disciplinary tools were the 'weapons' of disciplines. On one hand, the disciplines were not willing to change their weapons easily. On the other hand, changing tools naturally occurred as people tried to keep up with new technologies and possibilities within their discipline. However, these efforts typically remained limited to local practices, which did not facilitate knowledge sharing across the entire project. Tools without accompanying social practices and procedures were found to be ineffective.
Procedures	Except information exchange between client and design team, there were no common ground rules on how tools should be used throughout the design process: how physical settings should be planned, how actors should engage in social interactions, exchanging artefacts informally prior to the design process. Nevertheless, each project developed project-specific practices albeit often on an implicit basis.
Social Practices	Despite the large number of people participating in the projects, there was no explicit attention to organize distant and face-to-face interactions among people. In both cases, the actors constructed a project culture due to the long duration of projects, and due to the same goal within the division of labour. However, a project culture may not always result in a shared view regarding knowledge sharing. Although there were limited explicit KSS in LCBPs, there was always a group of actors who intuitively conducted activities and planed operations to perform knowledge sharing across organizations.

Table 10
Summary of the main insights from Chapter 5.

§ 6.3 Confirmation of the Results

As indicated in Chapter 3, an expert panel was organized to confirm the generalizability of the research results. Eight senior-level practitioners who had experience working in different LCBPs were invited. Seven of the invitees participated. The experts were selected from different disciplines in order to create an inter-disciplinary and inter-organizational setting (see Table 11). Experts became the representative of their knowledge domain findings from different organizational and disciplinary perspectives. The aim of this expert workshop was to gauge whether the findings from these two case studies were in line with the experiences in other large complex building projects; and to what extent the findings could be generalised.

The expert panel was held on 30 January 2012 at the Faculty of Architecture of the Technical University of Delft. The experts were selected based on the following criteria: 1) they had the senior level of experiences in LCBPs, 2) they represented different disciplines (perspectives on LCBPs) therefore taking different roles in LCBPs. The list of the participants is as follows:

Number	Role	Organization
Expert 1	Lead Architectural designer and Owner	An award-winning architectural firm
Expert 2	Design Manager (Architecture)	An award winning, globally-known architectural firm
Expert 3	Project Manager	Project Management Body of the National Railway Network Infrastructure
Expert 4	Design Manager (Infrastructure)	Large Scale Contractor
Expert 5	Social Science Researcher	Public university and owner of a consultancy company
Expert 6	Project Manager	A Greater Municipality
Expert 7	Architect and Director of Execution and Finance	An architectural firm

Table 11

List of participants of the expert workshop

The program of the expert panel is provided below in Table 12.

Time	Subject
16.00	Arrival Welcome and Short Introduction of the Attendees
16.30	Session 1: Presentation by PhD Researcher on barriers to Knowledge Sharing Strategies (KSS) (cf. findings of Chapter 4)
16.50	Individual feedback forms addressing uniqueness, temporariness, and complexity of the LCBPs
17.00	Panel Discussion about generalisability of the results for overall LCBPs
17.30	Session 2: Presentation of the Knowledge Sharing Strategies based on two case studies and the results drawn in Chapter 5 by the PhD researcher
18.00	Individual Feedback forms
18.30	Panel discussions on the completed feedback forms
19.10	Session 3: Presentation of the practice implications by the PhD researcher
19.30	Reflections from the participants to verify the recommendations for LCBPs
20.45	Closing

Table 12

The program of the expert panel

The expert panel was organized in three sessions based on empirical data analysis represented in the two chapters (Chapter 4, and 5). Each session comprised 20 minutes of presentations, 10 minutes of filling in individual feedback forms, and panel discussions facilitated by the supervisory team. All seven experts were actively engaged in this confirmation process. The panel took approximately five hours (see Table 12).

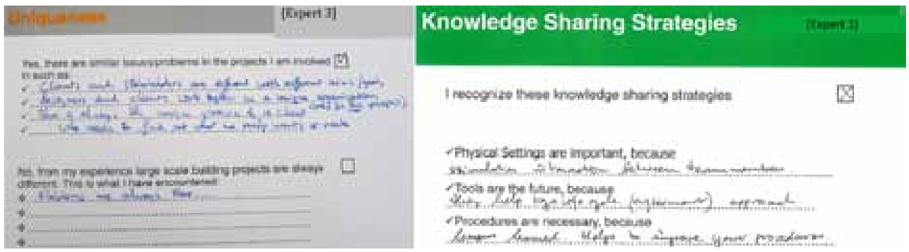

Figure 78
Examples of forms completed by the experts

The supervisory team of this study was present throughout the panel. Each supervisor took a different role such as leading the conversations, observing, and re-directing the practitioners' insights towards the results (when necessary). Beside the supervisory team, a student assistant took notes during the discussions, recording both collaborative and focused feedback moments, through picture and voice-recording methods.

During each session, the expert panel members received feedback forms (see Figure 78). When filling in the forms, the experts drew initial comments regarding the results that had been presented without any interaction having taken place between them, as illustrated in Figure 79.

Figure 79
The individual feedback filling moments during the expert panel

During the discussions, the experts provided relevant examples to validate the research results from their own experience or from the current projects. These discussions were facilitated and notes were made on a flip-chart by the co-promoter (see Figure 80 and Figure 81). A student assistant also digitally recorded the discussions.

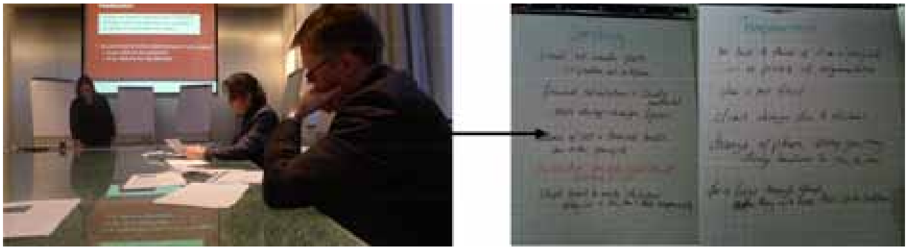

Figure 80
Individual responses and flipcharts

Figure 81
Final panel discussion

§ 6.3.1 Confirmation of The Resuls on Barriers of Knowledge Sharing Strategies

The seven practitioners commented on the presented results with a high level of alignment to the research results. Both the alignment of the experts and the issues that they disagreed on are presented and reviewed below. Uniqueness of Large Complex Building Projects

The seven experts initially reflected on the common attitude of the practitioners who conducted an investigation into the two LCBPs: each project is unique, but only to a certain degree. The majority of the experts (Experts 2, 4, 5 and 7) commented on the uniqueness of social structure in each LCBP. The perception of the technical characteristics of each project was the concern of three experts: Experts 1, 7 and 3.

A. Unique Issues of LCBPs as identified by the Experts on the Feedback Forms	
Expert 1	*Different* stakeholders
Expert 2	*Difference* between design and technique used in each LCBP
Expert 3	*Different* client and stakeholders Unique process of a client to find of finding out the real needs Unique organization formed by designers and clients in each LCBP
Expert 4	*Different* parties involved in each new LCBP leading to *different* team-member collaboration influenced by the *different* project leaders and client forms (i.e. professional vs. non-professional)
Expert 5	*Different* cultural context (Asian, Anglo-Saxon, American) *Different* team collaboration
Expert 6	*Different* clients (non-professional/professional) and *different* goals, perspectives and incentives and location
Expert 7	Unique project members, country making projects unique *Different* habits of team members social structure of each project which affect the degree of collaboration of actors, Unique culture of organizations Changing scope, timetable and team
B. Generic Issues of LCBPs drawn by the Experts on the Feedback Forms	
Expert 1	Fluidity of decisions
Expert 2	Changing horizon over time and missing procedures about changes
Expert 3	Always same problems encountering
Expert 4	The necessity of a frequent communication to get the project moving Repeated approaches such as at building permit
Expert 5	Changing scope; social construction of time/outcome and different project narratives; development of a project culture over time
Expert 6	Delays, budget overruns, misinterpretation, views to realize the timetable
Expert 7	Cost overrun, dividing up the design into manageable parts, too ambitious and unrealistic time frames and budget

Table 13
Summary of expert feedback on issues of LCBPs

The feedback received from the experts on the unique and generic issues of projects is reported in Table 13. This feedback has revealed several matters. Firstly, their feedback exposed that the experts had incorporated the differences of projects in the category of the uniqueness of projects. However, when experts wrote down their issues, they distinguished the 'differences' of each project and uniqueness of projects separately (see the italic and underlined words in Table 13). This shows that the experts mainly categorized the projects as being unique, because of how each project differed. However, they still have not made an implicit distinction between the two categories.

Secondly, the experts' distinction between unique and common issues of LCBP revealed that the unique issues (comprising the differences) are more about the characteristics of projects and they can be identified prior to the start of the project. As an example, stakeholders, timetables, project members are more the 'project-basics', which are often known before the design process has started. The generic issues were about the changes in the timetables, project members, stakeholders or their changing decisions (see Experts 1, 2, 3, 5, 6 and 7 in the B Section of the Table 13). This feedback received by the experts, in fact, confirmed that the uniqueness of a project does not make the project problematic, but that the changes regarding these unique characteristics of the project do.

If one synthesizes each issue that the experts stated as unique, one interpretation can be made; *project members* who uniquely come together form a *unique project organization*, which results in a *unique project culture*; the client *defining the project needs uniquely* in each new LCBP. This interpretation then becomes yet another example of how existing assumptions regarding project uniqueness and leading actors can become inertial against any actions towards KSS. Controversially, the same experts provided feedback on the common characteristics and they implicitly confirmed that the process of how each unique characteristic is regarded in each LCBP is similar. Moreover, the unique issues raised by the experts pointed out the vast social aspects of LCBPs, such as the formation of design teams, and the varying cultural contexts, whereas the common issues serve more as technical reflections of these social aspects. As an example, Experts 1,3,4,5, and 7 pointed out that there was a unique combination of team members and stakeholders. The same experts stated the changing decisions (Experts 1, 3 and 5), repeated approaches (Expert 4), the delays, budget-cost overruns, ambitious timetables and misinterpretations are the commonalities. These commonalities are the generic problems that have been investigated in this research study and which are the results of insufficient collaboration among the stakeholders (including the clients) and the design team members that involve both, whether it has to do with changing the decisions or dealing with the decisions that have been changed. The feedback forms revealed the underlying problem that lies behind the perception towards the uniqueness of each project; either the uniqueness or the differences between each LCBP does not motivate actors to take action to deal with the recurrent problems and to leave actors in the 'no-action' mode regarding the deliberate project-specific KSS.

The panel discussions provided an opportunity to elaborate on the research results and to obtain more insight from the experts, which either ensured or synchronized their different perspectives. Following the panel discussions, the experts agreed that the project actors needed to combat these existing prejudices, and to look beyond the picture that had been given of the project specifics, and to abandon the 'no-action' mode regarding KSS. The exemplary quotes follow below.

Focusing on that uniqueness was seen as hindering joint efforts between organizations (Expert 4), or as a myth that blocks actors from thinking further about making any investment in projects (Expert 7) and from recognizing that a project location is simply a 'city' that requires similar regulations that are also not solely about geographical uniqueness anymore (Expert 6).

The expert responses during the panel discussions confirmed our research results on the three barriers and counter-arguments towards the first assumption. Uniqueness is not a barrier to designing and implementing KSS, as indeed, it is an argument to do so. It is the mind-set that prevents actors from designing or implementing a project-specific KSS, and not the unique components of projects. Nevertheless, what tends to be forgotten is that projects are initiated due to their unique character. Uniqueness is not something that should be avoided. On the contrary, it is often precisely what is initially desired. Thus, LCBPs are indeed unique but they comprise generic components. Therefore, establishing knowledge sharing strategies makes sense. The experts' comments revealed that it is important to identify what makes each LCBP unique and different, and how these unique characteristics are reflected in the design process.

§ 6.3.1.1 Temporariness of Large Complex Building Projects

The seven experts also commented on the discussion regarding temporariness. Five of the seven experts agreed that LCBPs last long enough to accommodate KSS prior to the panel discussion session. After the panel discussion, all seven experts confirmed that, in the context of LCBPs, the duration of projects is long enough to warrant designing and implementing KSS.

A. The Views Confirming that LCBPs are long enough to design and implement KSS	
Expert 1	When organizations are legally bonded, the list of requirements is better defined, and client is more disciplined
Expert 2	When participants are convinced to share knowledge
Expert 3	The unique temporariness of the project organization requiring knowledge sharing
Expert 4	Once there is a critical mass moving towards knowledge sharing
Expert 5	If KSS leads to better LCBPs which are change projects
Expert 6	When decided open or closed structure for knowledge sharing and when dealing with less number of people who can be critical opponent and provide feedback to manage knowledge sharing
Expert 7	No remarks
B. The Views Supporting to that Projects are temporary	
Expert 1	No remarks
Expert 2	For certain companies involved to work together on specific basis
Expert 3	LCBPs are uniquely temporary
Expert 4	Different phases accommodating temporary involvement of organizations
Expert 5	No remarks
Expert 6	Parts of projects can be temporary
Expert 7	No team culture is developed, since team members change all the time

Table 14
Experts comments on temporariness as presented in Chapter 4

As seen in Table 14, six of the seven experts confirmed that LCBPs provide a long enough time to invest in knowledge sharing. Although the six experts validated the sufficiency of the LCBPs' duration for KSS implementations, their feedback pointed out that different drivers are required to design and implement KS and achieve KS. The experts drew conditions to ensure knowledge sharing throughout the duration of LCBPs. Expert 1 emphasized the necessity of an explicit and legal bond among the actors. This legal bond is not only to ensure the commitment of actors, but also to manage the requirements and 'discipline the client'. Expert 1's concern points out changes in projects, and therefore implicitly links the complexity and fluidity discussions with the duration of projects accommodating KSS.

Experts 2, 4, and 6 emphasized the social drivers required for achieving KS. Expert 2 put project actors onto the focal point of a KSS, as highlighting that it was necessary to convince the actors, whereas Experts 4 and 6 dealt with the number of actors (namely 'critical mass' and 'fewer actors' were needed) that could be targeted and 'convinced'. Once this they have been convinced, the 'critical mass' that Expert 4 referred to as the dominant shared project behavior towards sharing/not-sharing attitude can be directed towards knowledge sharing. The comments made by Experts 4 and 6 raised two contradicting views towards the group of actors that can be targeted and used as KS promoting agents.

Expert 2 particularly drew attention to the necessity of the actors' commitment. This was associated with the 'critical mass' issue raised by Expert 6. On the contrary, , Expert 6's view revealed an opposition towards the number of people who should engage in KS. Expert 6 argued that 'fewer actors' were needed for targeting KS in order to manage the implementations and achievement of KS. These two views might be seen as contradictory views, but it can also be contextualized as using CoPs as a driver to implement KSS and sustain knowledge sharing among actors. The small number of people refers to the selected individuals that form the core part of a CoP in a LCBP. These core members are committed to implementing KSS and they have a holistic role to influence the team members to set and share the common goal with other actors towards KS as forming and directing the critical mass towards sharing attitude. At this point, the feedback of Expert 2 paid attention to the definition of the outcome of any KSS, prior to the implementations. Expert 2 implicitly points out the concern that what a KSS will deliver or how it will benefit the actors so that the actors commit to a shared implementation across their organizations. This revealed an interesting issue to define in this research; can the tangible effects of a KSS that can be anticipated prior to the implementation help pave the way in convincing the actors about shared implementations?

When I review the disagreement experienced by the experts on the temporariness, five experts had additional comments on the actual temporariness of LCBPs (Expert 2,3,4,6 and 7). Experts 2, 3, 4 and 6 raised the issue that projects are temporary for certain organizations that particularly involve phases. Their shared remark highlighted a necessity for this research; the definition and selection of the organizations that should be involved in a KSS either continuously or a periodically throughout a LCBP. Although the key project organizations with which this research study is concerned had been previously clarified in Chapter 1, and although the analyses of the two cases were done based on these selected key organizations, this definition needs should be made more explicit.

Another disagreement arose when Expert 7 referred to the high turnover rate of individuals. However, this was one of the findings presented in the category 'LCBPs are not temporary, people are'. Expert 7 implicitly confirmed this and raised several issues regarding the duration of projects and the project culture that can be either facilitate or discourage knowledge sharing among the actors.

Expert 7's 'no team culture' comment proposed that individuals form a team's culture. Thus, throughout the project, since individuals often change (designers and managers) the team culture cannot be set. However, as reviewed in Chapter 2, the individuals who take part in projects are never present in a project team solely with their own perspectives and attitudes. Although the personal characters influence the way the individuals behave, they always act as representatives of the design organizations and pursue the agenda of their own organizations. Therefore, project members never solely represent their personal values, but their organizational culture that influences the way that individuals behave in a project. Therefore, the culture in a LCBP is an assemblage of the organizational culture that the project members bring to the table. As long as project organizations are involved in a project, the project culture is formed by these organizations for the duration of the project.

During the panel discussions, Expert 7 noted that the changing of personnel should not be a barrier, but instead should be viewed as a challenge to be overcome. He added that long duration of projects makes the end-result almost impossible to estimate. He related his experience in the small-scale projects as "*small-scale projects, the outcome is almost certain, but in large projects it is impossible to confidently estimate the final outcome at the beginning of the project.*" This view contradicted Expert 5's view states that the anticipation and pre-definition of the benefits of a KSS are needed in order to involve actors in knowledge sharing. The crucial issue emerges as how to define the anticipated benefits of a KSS, since the end-result of a LCBP is quite difficult to define.

The experts' feedback confirmed that the LCBPs provide enough time to design and implement KSS. However, it is important to define the shared objectives for actors (as well as to define who to select and integrate into KSS), and to have a clear shared vision that provides the actors' commitment towards fulfilling the implementations and engaging in knowledge sharing processes.

§ 6.3.1.2 Complexity of Large Complex Building Projects

Subsequently the seven experts provided feedback on the results presented by answering two questions; "Yes, I agree that the problem of complexity is in a constant state of change." And/or "No, I did not experience the constant change as a problem. But I was faced with other problems such as…" The summary of the feedback is presented in Table 15.

A. The views confirming that the problem of complexity is constantly changing.	
Expert 1	Change of parties; change of budget; change of people and change of regulations
Expert 2	*No remarks*
Expert 3	Lack of cultural coordination between different disciplines/specialist working together; different interests of clients in parts of the building; integration between different parts of the building (architecture, HVAC installations); different users and functional interests (i.e. trains/busses/travellers/cars/bikes etc.)
Expert 4	The difficulty of organizing and synchronizing the development of the project which moves the undefined towards defined by changes
Expert 5	Change in phases; new/other competences needed in new phases; interventions from political/public context
Expert 6	Change as a part of the game; it is a problem when project is focused, rather than the process
Expert 7	*No remarks*
B. The views stated that experts did not experience the constant change as problem but others such as	
Expert 1	*No remarks*
Expert 2	Different views to inform relevant decision makers
Expert 3	*No remarks*
Expert 4	*No remarks*
Expert 5	Fighting spirit
Expert 6	*No remarks*
Expert 7	The problem is not much about the changes, it is when putting the puzzle pieces together

Table 15
Expert comments on complexity discussion reported in Chapter 4.

As seen in Table 15, 5 of the 7 experts confirmed that the problem is not about the complexity itself, but the constant changes that take place. However, the problem occurs while decisions are changed (*changes as a part of the game*) for the elaboration of the design (*moving from undefined to the defined*).

Expert 3 exemplifies the first one as emphasizing the client's perspective that needs 'cultural coordination' and he cites the client's need to be aware of the different interests of the client organizations while integrating different parts of the project. This statement already confirms the necessity of knowledge sharing and the implementations of KSS that facilitate an actor to collaborate and synchronize their perspectives throughout the project process.

The second view, which perceives changes as voiced by Expert 7 in both feedback forms and in the panel discussions, claims that *"the world we live is a changing world, society changes."* He stressed that the problem is not about changes, but "about the bringing the puzzle pieces back together." This view overemphasized the integration of particular moments, but it undervalued the synchronization of disciplinary practices while design work is undertaken. If changes are considered to be parts of reality and by not emphasizing where the problems occur in changes, this view implies that no action is required to manage changes in LCBPs. This research accepted that changes are a part of design iteration that is a process of elaboration of solutions and re-definition of problems. When there is insufficient knowledge sharing within the design team, lack of understanding of each other's solutions challenges this iteration. If the iteration is accepted and communicated (i.e. making changes is completed in the iteration explicit to the other parties with the reasoning), the integration of the design parts (different building parts or different disciplinary solutions) become less problematic or make the problematic changes known earlier. Expert 5 emphasized that the problems occurring in the handover process referred to the integration moments between different phases and confirms that changes need to be communicated, applied and synchronized prior to the handover. Thus, this revealed the necessity to deal with integrating the design solutions as early as possible.

In the panel discussions, the issue of cost escalation was raised. One of the challenges of LCBPs is to estimate the end-result and the process to achieve the end-result, The seven experts agreed with Expert 1 that changes of budget, timeframe, and scope are part of the nature of LCBPs: "*…you know your scope is much larger at the end…" Expert 3 confirmed this view:* "…It is an illusion to think that someone can actually predict the total costs of the project…" These discussions revealed the rule of thumb of contractors who routinely add 50% to the estimated budget. This rule illustrates that many actors accept cost escalations as part of the game. As the experts confirmed, the scope is one of the concepts that is socially constructed together with the design object, the complexity and change discussions revealed that it is difficult to manage these socially constructed concepts, because changes are part of 'the nature' of the process. Thus, these social concepts evolve implicitly and on a continual basis. This makes the changes that influence the design solutions of actors difficult to manage and synchronize, since there is no holistic approach that overarches capturing and managing changes in such projects and sometimes there is no awareness among the actors regarding the necessity of managing the changes.

Through synthesizing the experts' comments together with the research results, the three needs emerged with regard to an intended KSS for LCBPs. Firstly, the real uniqueness needs to be understood by the project actors when defining each unique and generic characteristic of LCBPs that influences the design process within the design team. Secondly, the actual temporariness needs to be defined by the project actors by defining the short-term and long-term characteristics of LCBPs and the short-term and long-term participants of the design team. Thirdly, the actual complexity must be known by the project actors who in turn will need to anticipate problems that might occur by defining the complex characteristics of LCBPs.

§ 6.3.2 Confirmation of the Results on Current Knowledge Sharing Strategies

The second session of the expert panel was meant to validate the results that had been obtained when responding to the answers of the second research question. Firstly, the experts were asked to confirm whether this study might be relevant to practice. All seven experts agreed that an inter-organizational knowledge sharing strategy for LCBPs was needed. Secondly, all of the experts presented KSS and its aspects through their own experiences by dealing with each dimension of the Knowledge Diamond framework. The experts remarked that in the LCBP that they were involved, they had been aware of the efforts that needed to be spent in order to deal with each dimension of the framework, but they also noticed that these efforts could form a part of a larger whole. Thus, the experts did claim that they never targeted all four aspects at one time or in one shared implementation. This led to the third confirmation, which was that the experts had agreed that a holistic framework is needed in order to enable practitioners to develop a deliberate KSS for LCBPs.

§ 6.3.2.1 Physical Settings in Knowledge Sharing Strategies

All seven experts confirmed the importance of the physical settings in knowledge sharing strategies. Each expert pointed out a different advantage of physical settings to tackle social processes of knowledge sharing such as ‘stimulating interaction’ (Expert 1), ‘enabling feelings of ambitions of people and their boundaries’ (Expert 3), ‘lowering barriers’ (Expert 4), ‘influencing behaviours of people’ (Expert 5), ‘enhancing productivity and relationships’ (Expert 6) and ‘setting shared-behaviour of people’ (Expert 7).

The advantages of physical settings were mentioned by all of the experts, thus exposing one common, but ‘invisible’ problem that was experienced in the practice: the existing disciplinary walls (boundaries) which hinder the understanding of what motivated people (feeling ambitions), building relationships, and setting a knowledge sharing behaviour throughout the LCBP. One interesting statement made by Expert 7 could be observed: Expert 7 had commented previously on the temporariness discussion claiming that a shared-culture cannot be set in projects, because people change in LCBPs. However, Expert 7 noted that physical settings could play a role in building a shared-behaviour that leads to a project culture. Thus, the expert emphasized that physical settings is a crucial dimension for building upon a KSS in order to build a project culture that embeds the knowledge sharing of actors. In the end, the comments referring to physical settings were detected as ingredients of building a project culture that promotes knowledge sharing, once the problems have been tackled.

Expert 2 raised the problem of discontinuity in the participation of the key players, particularly if a long-term setting had been established. Expert 2 pointed out that there was a limited amount of personal commitment, whereas Expert 7 commented that there is a high potential of clash occurrences that automatically happen by bringing people to the same physical setting. The problem that had been raised earlier by Expert 1 was already tackled during the discussions concerning temporariness, whereas the number of people was an issue in regard to targeting the implementations of KSS. Expert 1's comment referred to the difficulty in the presence of design leaders in each setting. However, in this research setting a knowledge sharing behaviour is not about being keen on some key players at a managerial level, but instead it is about forming a sharing culture that connect both designers and managers and also encompasses newcomers towards KSS implementations. However, the discontinuity of key players is a factor that still needs to be resolved. This discontinuity is in approval and transferring the decisions so that actors do not have delays due to awaiting decisions that need to be made by key players.

Expert 5 and 6 provided examples of how the problems associated physical settings may be resolved. Expert 5 emphasized the importance of establishing a 'professional culture' through critical review workshops that are formed by objective experts who are not the direct parties of projects. This recommendation connects the physical settings in order to take a role in forming Communities of Practice within a particular project through the experts' periodic visits. Nevertheless, this was through the help of experts who were not direct parties in the project team. Therefore, the 'trust' towards the experts by the project managers became important. Expert 6 stressed the importance of organizing both formal and informal meetings. He emphasized that the informal meetings have a potential to promote casual discussions, therefore people in the meetings loosen their boundaries. He stated that informal meetings are 'responsible-free' moments meaning that people do not feel the responsibility to record any decisions taken there. Additionally, when these informal meetings are organized by the actors in management level and lack clear purposes, the meetings result in unattended or results in unwilling attitude towards knowledge sharing.

The experts highlighted the fact that physical settings may not necessarily promote social interaction, if actors do not first clarify what they expect to achieve from these settings. The experts' feedback brought up the need to plan and clarify the actions that take place in these settings and the number of actors who should participate in the physical settings, the inclusiveness of the social and informal areas so that these settings can play a role in facilitating knowledge sharing in LCBPs.

§ 6.3.2.2 Tools in Knowledge Sharing Strategies

Six out of seven experts who commented recognized the supporting role of the tools for knowledge sharing in LCBPs as seen in Table 6.8. The experts' views towards this support role of tools distinguished between design and management practices. For the management support, the use of tools throughout their 'life cycle of a project' by 'creating work flows and good archives' were raised as an advantage. Both issues aligned with the results of this research as tools had been proposed in order to capture the project history. For the design support, the advantages of using tools targeted supported the social mechanisms of knowledge sharing such as 'cultivating discussions', 'collaborations', 'improving co-design and distant interactions' and 'enabling people to work on large number of topics'. The experts' comments focused on the advantages of using tools to promote distant interaction and passive knowledge sharing. However, each expert raised a concern regarding tools, as there are potential problems that can hinder achieving the proposed benefits.

All of the experts mentioned that there were potential problems and they drew attention to the different issues regarding the tools. The first issue became the problematic use of integrated design tools in LCBPs. Expert 1 raised the concern that such tools might limit the creativity, but without providing examples for possible limitations. Expert 4 criticised that tools are often not dynamic enough to match the speed of design practice. This perspective, which referred to 'limiting the thinking outside-of the box' and 'not being dynamic enough', matched the views held by the project architects in Case 2. However, through the panel discussion, it was revealed that both experts did not experience in using an integrated design tool comprehensively in a LCBP similar to the project actors of Case 2 (even though these project actors had a chance to engage in a 3D model that had been initiated by the engineering firm). This revealed that there is resistance to integrating the design tools into the current practice of actors. This resistance limits embedding new technologies, which can be used to their full extent, as proved in this research study.

The second issues Expert 3, Expert 5, and Expert 7. The experts' comments revealed different dimensions of the commitment problem. This issue was a subject of joint-discussion. The experts' comments pointed out that the organizational tools conflicted with the inter-organizational tools in regard to the issue of commitment. This issue was raised by the experts who linked the findings of Case 1, which was about using an advanced knowledge management system for organizational development and the reluctance of project actors in Case 2 concerning the 3D design tool. The development of organizational tools may hinder actors from engaging in a shared tool, since they are used to their own systems. Thus, the interrelation (or integration) of existing organizational tools with the tools particularly selected and positioned in a KSS became important. Furthermore, regarding the tools of KSS, the experts' feedback highlighted the planning of the implementations, resources and the estimated advantages to using these tools. This planning becomes important to get support from people and to avoid 'technocratic implementations' if the planning leads to guidance for people. Although these highlights had already been incorporated in the results of this research, the experts placed an emphasis on these issues made sure that the results were valid in current practice.

§ 6.3.2.3 Procedures in Knowledge Sharing Strategies

The seven experts agreed that procedures are needed to formalize the actors' actions and to establish legal boundaries for each organization participating in projects. The advantages of having explicit procedures are aimed at the different aspects of knowledge sharing. Firstly, the advantages of explicit rules are targeted at regulating decisions and how these decisions flow among people. This advantage of having procedures that have been aligned with the discussions concerning the complexity and changes in LCBPs and this also confirmed the necessity to regulate and manage change and complexity. Secondly, the regulating role of procedures was stressed so that the experts did not mention unnecessary sets of rules to be followed.

Two experts brought up their concerns regarding the procedures as they might limit people's freedom if they are too strict. Besides being strict, another concern was to avoid having 'check-lists' and specialized rules that are suitable for the profiles of organizations and their varying practices. The comments made bythe experts revealed that there were existing problems in how people interact, with a subsequent lacking of practicality in matters that might result in not explicitly incorporating previous experiences in new projects.

Expert 1 drew from his previous experiences of creating a successful format based on the Design, Build, Maintain, Finance, and Operate (DBMFO) contract as a formula for regulating projects for a duration of 25 years. These contracts help to establish a legal framework for working with actors such as designers (architects, landscape, interior, urban and graphic design/art), builders (developer and cost). This also included facility management, financial and legal parties. However, the power of legal bond on paper does not always result in social bond between actors, as was experienced in Case 1 between architectural and engineering firms.

The comments made by the experts supported the result that procedures can improve the boundary crossing of people, as procedures deal with which boundaries need to be crossed and preserved and by which means. However, procedures should target carefully what they regulate. At the end of the panel discussion, the experts perceived that procedures should not only deal with regulating and overcoming the interaction problems, that they should also be integrated in the contracts.

§ 6.3.2.4 Social Practices in Knowledge Sharing Strategies

As can be seen in Table 16, 6 of the 7 experts confirmed that social practices help to share knowledge. These experts elaborated that social practices are the main drivers of projects influencing a shared-culture, enabling knowledge sharing and creating a shared-understanding, thus building trust and relationships between people, and therefore necessary for team-building. It could be observed that Expert 1 neither positively nor negatively commented on the social practices aspect. During the discussions, the social practices were elaborated on and they received additional attention from the experts. This revealed a concern that social practices might refer to a difficult dimension to express and that might be found challenging before they can be fully understood prior to any implementation of KSS.

The comments revealed that social practices had been perceived as a focal dimension that enacts and makes other aspects work towards achieving knowledge sharing in LCBPs. The experts comments' presuppose that social practices are the way that people 'build relationships', 'gain trust', and set a culture of 'sharing knowledge', once there is a 'proud factor' (which referred to the same-commitment towards the project goals) and organized face-to-face settings. The experts' views enforced that social practices become knowledge sharing practices, once necessary conditions have been set (such as creating a trusted and shared-atmosphere).

After the panel discussion, a closing round was held in order to summarize the views held by the experts with regard to the four aspects of the Knowledge Diamond. Physical settings were regarded as being essential, as people need to meet face-to-face and interact with each other in order to determine whether or not their views are aligned.

The planning of these settings became important so that they could accommodate actively used both informal and formal interaction spaces. However, the crucial issue is that these settings do not determine the existence and formation of the social structure.

Tools were believed to be the future of the design, but it became important to define the selection and clear purpose behind the use of tools prior to implementations. This stressed the timing of when the tools should be introduced. Furthermore, the tool discussions revealed that new social skills are necessary for distant interaction. The expert panel highlighted the interrelation between tools and physical settings as distant interaction (virtual collaborative work), which would need to be taken into account in designing workspaces.

Procedures were found to be necessary and they were usually missing in current LCBPs, as long as they were designed to make the boundaries of organizations clear and not become too strict to discourage people.

Social practices were regarded as a focal aspect of a KSS and seen as important mechanisms of knowledge sharing. However, the way that people enact each aspect of KSS such as physical settings, tools, and procedures need to be encompassed. Social practices required the awareness of actors when creating a shared project culture that facilitates knowledge sharing, and which considers the existence of the different sub-cultures in the project environment, and delegates the power (as setting the designers free in relation to the decision making to a defined extent) in order to avoid that social practices only benefit decision makers.

		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Physical Settings	Benefits	Stimulate interactions	Offer advantage to the participants	Enable 'feeling' the ambitions of people and knowing their boundaries	Lower barriers to s hare knowledge	Enabling influencing behaviours (but determine them)	Enhance productivity and building relationships	Set a shared-behaviour amongst people
	Problems	Absence of key players (continually)	Limited to the level of personal commitment	-	-	Does not function without people	-	Accommodate clashes between organizations that hinder setting a shared-project culture
Tools	Benefits	Help actors during the life cycle	-	Support and serve to people	Enable people working large amount of topics, themes, create work flows, and good archives	Help to cultivate discussions and collaborations	Helping management of projects	Improve co-design, distant interactions yet
	Problems	Limit creativity 'out of box'	Misused by people	Cost efforts & energy, have a danger to derail the main aim 'supporting people'	Not dynamic enough	Stimulate technocratic, instrumental perspective	Have a danger to not embrace all people due to additional learning required	Problematic commitments between people not explored enough
Procedures	Benefits	Improve design process by adding lessons learnt	Provide continuity of regulations	Necessary to stream up the work and come to decisions	Shape the flows of decisions, interactions and avoid chaos and risks	Former experiences enhance the rules	Ease the way people think and behave when integrated to the contracts	Bring practicality to the way that things are done
	Problems	-	Limits the freedom	-	-		No check list works	Avoid being strict
Social Practices	Benefits	-	Main driver of projects, influences shared-culture and atmosphere	Necessary to form sharing group to work 'a basic human need'	Enable absorbing knowledge and understanding of others	Enable sharing knowledge, gaining personal trust and setting social relationships and networks	Enable team building	Beneficial
	Problems	-	-	-	-	-	-	Only lead designers

Table 16

Summary of expert feedback on the Knowledge Diamond Framework

§ 6.4 Practice Implications

In this section, the third research question will be answered, namely which recommendations can be made based on the findings of this research with respect to improving knowledge sharing in LCBPs.

Based upon the experts' responses to the results presented, the practical implications of this research can be discussed. Recommendations are provided for both the practitioners who take part in the design itself, and the practitioners who are involved in the design of the project-specific KSS for future LCBPs and who are members of client teams working on large complex building projects.

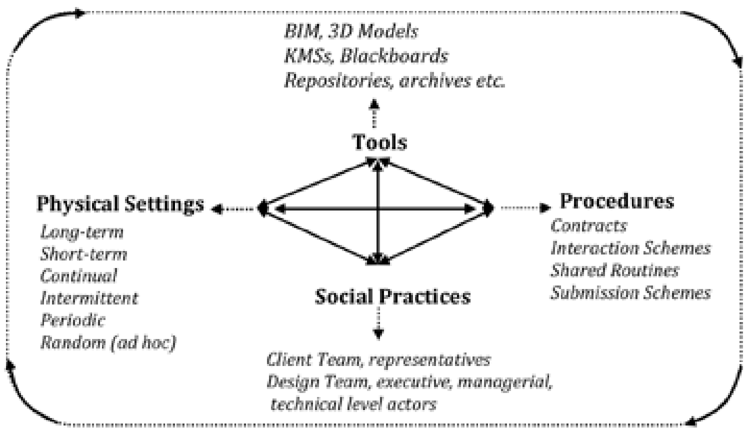

Figure 82
The Knowledge Diamond Framework (© Bektaş)

The practical recommendations will be discussed using the Knowledge Diamond diagram as a strategic framework for KSS (see Figure 82). This diagram and its dimensions offer practitioners the possibility to select and combine insights that are useful for the unique projects they are involved in. Practitioners need to ensure that the insights selected are in harmony with the Knowledge Diamond. The Knowledge Diamond does not provide rigid prescriptions for solving organizational problems. There is no 'one-size-fits-all' solution. The Knowledge Diamond is a high-level strategic framework that functions as a lens for practitioners in order to precisely analyze the current situation in each dimension. This analysis can help practitioners to design and implement project-specific KSS through elaborating, planning, and linking the dimension-specific activities to the different actors in order to cultivate the knowledge sharing processes in large complex building projects. Below, several options will be presented which can assist practitioners in selecting and defining the combinations that will enable them to tackle knowledge sharing problems in specific projects. While using these combinations, practitioners are able to develop their project-specific knowledge sharing strategies.

§ 6.5 Designing a Project-Specific Knowledge Sharing Strategies

In order to develop an appropriate KSS, practitioners first need to have an in-depth understanding of the characteristics of the LCBP that they are working on as a team. Practitioners need to determine which organizations are to be involved and what their distinct contributions to the design project should be for each phase of the design process. In other words, practitioners need to come up with a document that indicates which organizations work continuously and which organizations join the project intermittently. This document should also include the problems anticipated that the actors might face throughout the duration of the project. This document helps the practitioners to plan their collaboration successfully. One might argue that such a division of labour in each phase would appear obvious, because the organizations involved have already developed their project schedules, and the clients have made contractual agreements with the designing organizations, etc. Nevertheless, an explicitly formulated, and clear, visual presentation is needed to make each actor share the same understanding of the overall project.

Apart from such an 'organizational X-Ray', the characteristics of a given LCBPs also should be formulated explicitly. Practitioners need to explicate both the unique and generic components of the project. This helps them to deal with occasional changes, to manage provisional components of projects, to adjust the time schedules and to clarify the issues that make the project complex (i.e. functional/technical/technological/ organizational complexity). The practitioners can adapt the tables, presented in this study, which are used to analyze the three characteristics of LCBPs (see Chapter 4) and eventually, additional project specific characteristics to these tables.

In addition to the formulation of a common and shared knowledge of what the project is about and of what is needed to make it successful, practitioners should organize a kick off meeting and select a steering group that is responsible for the management of the KSS. This steering group can be either one of the core design teams (i.e. engineering or architecture) or a project management team consisting of client representatives. This steering group does not have to be a permanent one. Different design organizations can take over the management role in different phases of KSS. Rotating the management role in the project organization can create a democratic environment in which each design organization will have a sense of project ownership due to their active role in managing the KSS. When the managing role of KSS rotates, extra attention will need to be paid to the handover process. Being aware that a managerial handover will take place can put pressure on the organizations involved, and this will urge them to inform each other more explicitly or to intensify feedback session, and to take deliberate action towards the strategic implementation.

Once the management of the role of a KSS has been established, practitioners can start carrying out their project-specific KSS. Although up until now, all recommendations have focused on a bottom-up development of the KSS, the actual implementation is a combination of a bottom-up and a top-down approach. Firstly, practitioners need to make be aware of the fact that any KSS requires a high level of commitment regarding both the design and the client organizations in order to allow the managers to direct the designers in a clear and undisputable direction. Secondly, designers representing the 'bottom-level' need to be aware of the fact that there is a well thought-out KSS and that they are responsible for pre-planned operations. An on-going dialogue is needed between designers and managers. Managers need to clarify why a particular KSS has been selected and designers need to respond to the plans of their managers and to the intended KSS. Managers need to gather the feedbacks of their designers and to adjust their KSS, when needed. Along the way, managers also need to evaluate to what extent the intended KSS is realized and what is still to be done.. Therefore, KSS implementations do not require a bottom-up or top-down approach, but instead they call for more of an elevator approach that moves between different levels in the project and is open to adjustments. By following such an elevator approach, practitioners become familiar with the emergent strategies and/or local practices. By being aware of these emergent strategies, practitioners can clearly evaluate the strategies and properly include them in the intended KSS .

In designing their project-specific KSS, practitioners should determine their needs and the type of strategic implementation that fits the best. During this process, I recommend using the Knowledge Diamond as a strategic framework. By using this framework, practitioners can define the implementations and plan the operations that support the development of knowledge sharing processes of actors in LCBPs. In the next sections, recommendations for each dimension of this Knowledge Diamond are provided.

§ 6.5.1 Physical Settings

The experts in the validation workshop pointed out that practitioners need to plan the continuity and the occurrences of physical settings systematically. The dimension 'Physical settings' of the Knowledge Diamond contains several options, to be selected and organized, depending on duration (long-term/short-term), frequency (continuous/intermittent), and frequency (periodic/random). The duration refers to the length of time: are the physical settings needed throughout the project or only at particular moments. An example of the former is to plan long-term settings in different phases during the project. An example for the latter is the planning of short-term settings in order to complete a phase by verifying and controlling its deliverables, overlapping submissions, etc. In both long-term and short-term physical settings, the actors' participation is needed to design the settings layout. During the design of the layout of physical settings, it is advisable to devote attention to the potential interaction between actors and to the planned workspaces. However, the physical setting should not dictate the way actors should behave. The practitioners need to be able to reset the layout over time, based on the actors' responses to the original design of the physical settings.

If a long-term, continuous physical setting is needed then the practitioners should pay extra attention to the so-called 'floor-plan'. A floor plan consists of both informal and formal interaction areas. Physical settings may pose potential barriers that might generate additional boundaries (i.e. a rigid attitude towards interactions between actors who belong to different organizations). The design of these settings needs to avoid these barriers. Moreover, practitioners need to pay attention to the focused-working areas of the disciplines, as these areas are the knowledge islands in which designers spend the majority of their working time. When aware of this, the practitioners may consider the option to design the long-term physical setting in a form that supports the functioning of a small cross-disciplinary design team. In that case, the design of the physical setting reflects the division of work in LCBPs. In doing so designers who work together in the same division are physically brought together on the same 'division' island, instead of being dispersed over distinct discipline-oriented islands,. These cross-disciplinary working islands can ease the overlapping of multi-disciplinary design solutions and control the recursive loop between different disciplines. Each physical setting design should explicitly deal with the interfaces of the sub-cross-disciplinary teams. One option for dealing with these interfaces can be the rotation of designers in such a way that each individual design team member works in different divisions and has the opportunity to develop a better understanding of the overall project.

If a short-term physical setting is considered, practitioners should carefully define the frequency of use, the content, and the location of the short-term physical setting. Since short-term settings bring actors temporarily together in the same physical environment, practitioners should take into account the job characteristics of the participants, their roles and engagements, the content, the purpose and the outcomes expected from the physical settings. Practitioners have options to plan the sequential meetings rigidly or defining flexible schemes that can be updated over time. Furthermore, practitioners also should define whether the occurrences of short-term physical settings refer to a periodic and rigid planning (i.e. once a month or every Monday, in the morning) or at random and whether the planning is flexible. In any case, practitioners need to pay attention to the specific contents, discussions, decisions, and actions taken in the settings. They need to prepare post-interaction notes/reports that explicitly draw the picture and nature of short-term settings regarding the design process. Practitioners should keep in mind that the outcomes of these meetings capture the design process and enable the actors to build a traceable project history thus creating continuity in recording the decisions that have been made by actors.

Meetings in short-term settings support long-term settings as well as the formalization of the interactions between actors. Meetings have the potential to improve the familiarity between actors and to ease the building of a sharing practice in projects. Meetings held in the 'division' islands are opportunities for observing the actual work culture of the distinct actors, and their way of discussing the design solutions. In this case, meetings could serve as 'transport vehicles' of the cross-disciplinary work culture. In order to allow more actors to have this opportunity, practitioners should rotate the participants of the meetings. This rotation will increase the sense of responsibility among the design team members since each time different participants need to summarize and translate the discussions that are relevant to the overall design. This will increase the familiarity between the different design organizations and it will smooth the dealing with interface problems, since the participant designers are not only involved in his/her own division of work, but also in the overall work (or the potential interfaces between the different work divisions). Based on the generic insights regarding the physical settings presented above, a number of detailed recommendations follow below.

§ 6.5.1.1 Long-term considerations

- The physical setting should be carefully designed, not only in order to improve the formal/informal interaction, but also to develop adequate focused-working spaces. The size of team, the physical layout, and the sizes of both focused and interaction spaces should not contradict the overall idea of a long-term physical setting, which has the potential to provide a shared work routine and to develop a project culture among actors.
- Designers should be involved in the design of their workspace. Their feedback, however, must be 'visible' to the implementers. If physical settings are not created in correspondence with the intentions of the users, the physical settings should be

revised. These revisions are based either upon the actors' feedback while using the settings, or upon a deeper understanding of the actors' intentions. The latter results from reflective dialogues between implementers and actors' who are expected to use the settings prior to the design of the workspace.

- Based on the division of work, cross-disciplinary working islands should be created, based upon the commitment between design team organizations. Sub-multi-disciplinary design teams conduct multi-disciplinary sub design processes that reflect the division of work. This division of work needs to be achieved by conducting a consensus with the actors. The rotation of actors should enhance a mutual understanding of the project as a 'meaningful whole'. This rotation can interrupt the boredom and monotony of work, which might easily occur when people work on the same project during a long time.

§ 6.5.1.2 Short-term considerations

In order to create short-term physical settings, practitioners should organize their own professional meetings and workshops, but the short-term settings need to be regulated and revised in order to function as a component of a KSS.

- The meetings should be periodically conducted in the different offices of the various design organizations. In doing so, the participants can benefit from having both active and passive knowledge sharing processes in the making of these settings.
- The physical setting should allow the designers to rotate between different teams, so that actors can meet their contact persons in different crews. By rotations, actors have a possibility to gather project understanding in a wider sense.
- Meetings should be held in different organizational settings and in such a way that the meetings enable the participants to observe the 'focused-work' -culture of the host organization.

§ 6.5.2 Tools

The 'Tools' dimension of the Knowledge Diamond encompasses several topics such as the purpose of the tools, the people, or parties that contribute to the development of the tools and the commitment of the actors. The recommendations regarding 'Tools' focus on the tools' purposes. These purposes are the design representation, the collaborative work module (i.e. BIM), the repositories (to capture the decisions taken which changed the design over time), the project intranets (the adjustments of company intranet to make it suitable to serve as a project intranet), and the virtual interaction/discussion boards (supporting interactions within focused-work environments).

Practitioners should introduce any new tool right from the start of the project. In that case, actors will have time to learn how to use this tool and to gain advanced knowledge by using the new tools.

When introduced at the beginning of a project, new tools could be inspiring. For example, in the case of BIM, the actors are able to develop various design concepts because BIM made the multi-disciplinary contribution visible. When practitioners introduce new and complicated tools at an early stage, actors can integrate the early inputs of the different disciplines and cultivate their own creativity by using the visual presentation of the obstacles in the proposed design concepts.

The early stage of LCBPs represents an appropriate time period for actors who uses new tools to improve the level of their competence. Practitioners have a reached a consensus regarding the type of tools that are to be use in the LCBP. It is important that the practitioners consult the designers who are going to work at the technical level and who are actually going to use the tools. In most cases, some individual members of a CoP might be interested in advanced technologies, the bottlenecks, and the possibilities of new technologies. These people are often familiar with the tools to be used and their input is crucial when selecting the tools. If possible, the tools should be pilot-tested in other projects.

All tool implementation processes require that periodically practitioners conduct review tests in order to evaluate the performance of the selected tools. These evaluations can be held at the end of each phase, and should include the representatives' opinions regarding the disciplines that are involved in the use of tools'. On the basis of these evaluations, a collective decision can be taken.

In the light of these concerns, I make the following recommendations.

- Consensus is needed at the very start of the project regarding which tools will be used. These should preferably be tools that were pilot-tested in advance.
- Tools that aim at inter-organizational knowledge sharing need to be introduced at the beginning of a project.
- One should explore the existing organizational tools in order to analyze to which extent they can support new inter-organizational tools, or even form the basic tool that the other participating organizations can use during the project.
- After having introduced a new tool, the designers who will use this tool, need to monitor the usefulness and performance of the tools, and to evaluate the performance in cross-disciplinary interactions, design representation, etc. The designers must share their feedback with the actors who are involved in the decision as to whether or not they should proceed accordingly.

- Tools should be presented in physical settings to depict the design decisions (such as recording crucial design workshops, meetings, etc.), which are to be retrieved later, when needed.
- The user guidelines of the tools need to be clearly illustrated in order to clarify who will use which type of tool, in which phase, and with which purpose.

§ 6.5.3 Procedures

The 'Procedures' dimension of the Knowledge Diamond should be planned as a legal shared services agreement that identifies the responsibilities, the roles, and the input of the design team organizations in the KSS. Practitioners need to define the selected KSS explicitly and they should identify the way that each dimension is enacted by actors. This procedure may refer to a separate set of rules that identifies and regulates the process of designing physical settings, the selection/use/commitment and evaluation of the tools to be used in the project, the division of work between the participating disciplines, which functions as a generally accepted basic rule for the allocation of their crew members, and the interfaces of the divisions.

Practitioners should formulate explicit rules that interlink each dimension of KSS, in order to make sure that the activities for each dimension are not performed independently from each other, but in a holistic manner. For example, procedures can be developed in order to formalize the interactions (i.e. formal meetings), to regulate their occurrence and the in- and output of the meetings. These procedures help to establish the history of the project, the so-called project memory, as mentioned earlier in § 2.4. The standardization of meetings and their outcomes can help to capture changes in design direction or design philosophy, which instigate the actors to build the project history. This project history can also help practitioners to deal with the high turnover rate of designers in LCBPs. Furthermore, the procedures enable the practitioners to create a task for actors to prepare periodic reports that describe the project history . At the end of each phase (i.e. the phase of the conceptual design, or the phase of the definitive design), this report provides information regarding the interrelationship between the current design and current scope of the client team. These reports provide input for the matching process between design and scope. Practitioners can either appoint designers or hire an external party to deal with this matching process.

Practitioners often introduce procedures depending on the different characteristics of the projects they are involved in. Given these concerns, I propose the following recommendations.

Procedures need to be explicit in defining the interlinking efforts dealing with each of the four dimensions of the KSS.

- Explicit procedures are needed in order to regulate the way the tools need to be used in the different phases of the project. These procedures entail the project purposes, and indicate who will be responsible for the tools.
- An agreement needs to be established regarding both the occurrences of the physical settings and the design of the physical settings. Each time when the settings change, the rules regulating how the physical settings are to enacted need to be revised as well. Rules that formalize the interactions in meetings with clients/architects need to be unambiguous in order to help, including the outcomes of the interactions during the project history.
- The procedures need to establish a clear, shard and collectively agreed upon division of work between disciplines. The roles and responsibilities for sub-projects and the interfaces should be specified.
- From the very beginning of the project, it should be regulated in procedures whether meetings and workshops are to be rigidly planned or randomly held.
- The procedures need to be aligned with the scope and the design processes. At regular intervals, the reasoning for the current design and current scope should be discussed among the design team and the client team.

§ 6.5.4 Social Practices

The recommendations for the 'Social Practices' dimensions of the Knowledge Diamond deal with the other aspects of KSS. Practitioners need to achieve a consensus about which organizations will participate in the selected KSS. This consensus should be reflected in the procedures in order to affirm the collaboration motives explicitly.

It is important that the practitioners define the different responsibilities, roles, and expectations of different groups, such as the group of lead designers, the group of designers, managers, steering committee members, etc. In that case, each group member will be responsible for conveying the decisions taken in the cross-functional groups (i.e. design leaders informing designers explicitly about the decisions which have been taken). As mentioned previously in § 2.4.6 regarding the physical settings, having representatives of distinct groups in each cross-functional group can open additional channels for communicating decisions, information, and discussions. Although this approach is appropriate to support the local cross-functional group interactions in the physical settings (due to the increasing need to grasp different discussions, and to engage in the social mechanisms of knowledge sharing), it can also be applied to distant group interactions. For example, when a design leader organizes a design review session by means of an online meeting program (i.e. Skype, Facetime software), each designer participant should observe carefully and take notes during the discussions. In both situations, the discussions held in the local cross-functional group and the virtual discussions held in distant interactions, as well as the post-interaction meetings should be arranged in order to make it possible that the individual members who were not present can be informed about the progress of the project and the decisions and changes.

The roles and expectations of each group member and the frequency of group interactions should be made explicit in the procedures. Furthermore, practitioners need to provide commonly shared project drivers (project objectives, project goals, or 'the proud factor') which provide direction for the implementations of the project. The organizational culture will steer the practitioners in their decisions on how to organize these inter-organizational interactions. This would benefit the performance of the physical settings where practitioners come together and engage in face-to-face conversations in order to synchronize their views regarding the contents of shared inter-organizational interactions.

The 'Social Practices' dimension incorporates the main recommendation regarding the tools, physical settings, and procedures. Social practices should be regarded as the 'glue' that connects the interventions in the other dimensions in physical settings, tools and procedures. Through social practices knowledge sharing in LCBPs is achieved. The recommendations for the dimensions of physical settings, tools, and procedures are all embedded in the recommendations for social practices. Practitioners should be aware that the dimensions of the Knowledge Diamond will only function as a successful component of a KSS, if their implementations take the people involved and their alignment with the implementations into consideration.

§ 6.6 Template for Designing Knowledge Sharing Strategies

There are six main steps organized in the template for designing and implementing project-specific KSS for LCBPs. The steps have been illustrated below in Table 17 and Figure 88.

Step 1: Understanding the nature of LCBPs

This step aims at helping practitioners to understand the nature of their projects by exploring the three main characteristics of LCBPs.

a Unique versus generic
b Long term versus short term
c Complex versus Problematic

By exploring these characteristics, practitioners can share the motivations, expectations, anticipations, and challenges that LCBP can face. In order to be successful, this step needs the joint efforts of both client and design team actors to be aware of the differences and similarities of the perspectives of actors, from the very start of the project. Practitioners can use the topics presented in Table 17 and elaborate or adjust them to their projects collaboratively.

A: Understanding the actual uniqueness through defining the unique and generic characteristics of LCBPs	
Regulations of Project Location	Identify the project location, its environmental, organizational, historical surroundings and portray authorities/stakeholders and their requirements
Shared Design Philosophy	As early as possible, identify the unique features of the design philosophy and find agreement regarding 'touchable' and 'untouchable' features such as the ambitions when the the project is finished, the ambitions that are not negotiable, and/or the ones which are open for discussion and can be compromised over time
Client Team	Identify the structure of the client organization, visualise the organizations on the front line (as in direct interaction with design team) and the ones at the background; then prepare a requirements list that contains each different requirement of the client organization that either contributes to the input periodically or continually; ask each organization to provide explicit regulations, requirements, wishes to elaborate the scope iteratively over time
Stakeholder Relations	Identify the stakeholders and their potential requirements and/or the regulations in a similar manner as done with regard to the client team Mind their role and involvement in the design process, since their presence may affect and even change the success criteria, which has been chosen at an earlier stage. Take precautions to prevent a major re-design due to possible ad hoc input if the relationships between the stakeholders have not yet been clearly established.
Design Team Relations	Identify the organizations that take part in the designing process for each time period (both those providing design service throughout the design process and those that intermittently join the process) Make the information available regarding the number of teams involved, the names of the team members, the details regarding their responsibilities. In this case, the organization will have a shared knowledge basis. Try to avoid creating 'project invisibles' such as people who may work in projects, but who are never noticed by other parties as being participants.
Shared Design Tactics	Develop a shared and appropriate design tactic to deal with unique projects, such as planning a shared division of work and manage interfaces explicitly.
B: Understanding the time schedule by defining short-term and long-term characteristics of LCBPs	
Working Period	Create a project time schedule for all organizations that will be (potentially or certainly) involved in the project. The schedule should include when the project was initiated, the estimated completion process, and which actors will be involved during which period. Keep in mind potential delays. Some of them may already be obvious from the start (practitioners are expected to reflect on previous experiences in order to see where projects might possibly delay, and to reflect on the overall planning and to signal optimistic time schedules)
Temporariness of People	Be aware that people will be involved in the project on a temporary basis. This may have consequences for the potential loss of project knowledge when people leave the project, so plan to share and capture their knowledge to minimize the effect.

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C: Understanding the current complexity and anticipating possible problems by defining the complex characteristics of LCBPs	
Number of Stakeholders	Make sure that the number of stakeholders is clear and pay attention to any organization that might possibly participate in the future
Interrelation with the surroundings (or other projects)	Check the relationship between LCBP and the surrounding projects in order to see whether the LCBP is a part of a greater project (i.e. transportation projects, bridges, underground/above ground projects, etc.) Be aware of the possible interference of other investment projects.
Program and Scope	Make the client scope explicit by aligning the efforts discussed under 'uniqueness'. Develop an explicit 'living' scope document that embraces all of the regulations including various specific details, which will become an official document to be commented upon, revised, and submitted at the end of each phase.
Division of Work	Find a balance between disciplines in order to agree upon the division of work and to use this division of work as a tactic to reduce the design complexity while paying extra attention to the interfaces; Form different design teams based on this division of work, and make sure that it is clear to all participants who are working in each division. Develop a shared interaction scheme for designers and managers who are responsible for the 'interrelation' of the divisions. Regarding the interfaces, either appoint an interface manager (but keep in mind that this additional role may increase the number of layers in the interaction scheme) or ensure that the designers have developed their own practices to manage their interfaces.

Table 17

Recommendations for practitioners to define the characteristics of LCBPs and to achieve a shared understanding of their projects

Step 2: Design The Focus of KSS (i.e. Tools, Physical Settings, and Procedures)

Once the practitioners have agreed upon the characteristics of the LCBP and that they understand both shared and individual motivations, ambitions and challenges of the project participation, they can start designing a vision and designing their project-specific KSS. Practitioners should then discuss the most appropriate focus of the KSS based upon a shared understanding regarding the nature of the LCBP. While designing their KSS, the practitioners may make use of the Knowledge Diamond framework as illustrated in Figure 83 and of the remarks stated in Table 18.

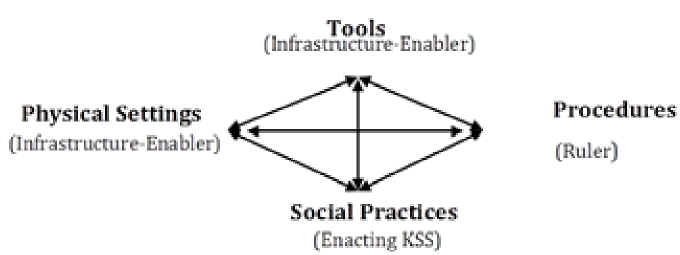

Figure 83

Four dimensions of the knowledge diamond and their possible roles in a KSS

Setting the Focus and Vision of KSS	
Concepts & Trends	Identify concepts, hypes, trends and the current developments in both design and client team organizations Explore the potential and the challenges in each concept in relationship to the nature of the LCBP as defined previously, and define the collective focus concept based upon the consensus reached by all of the organizations involved and the collective vision of KSS
Interaction between top to bottom and bottom to up	Set up a small multi-disciplinary research group consisting of designers who can identify the capacities, requirements and challenges of the selected concept and the high-level operations Enable designers to directly participate in the design process of the strategies, because they will be the ones who enact (or resist) the intended KSS and who can further develop any unrealized components. When the implementations do not match the requirements, the designers need to participate in a process to build a common understanding and awareness of all of the actors involved, which results in sense of ownership, which, in turn, could help to reduce the resistance to KSS.
Steering Role	Agree on a rotation scheme of the steering role within the design teams regarding KSS

Table 18
Recommendations for practitioners to build a vision for a KSS

Step 3: Identifying operations of KSS

After having defined a vision and focus of the intended KSS, practitioners can start the operationalization of their custom-made KSS. In this step, practitioners should explicitly define the operations to be carried out in each dimension and the interrelationships of the operations within the Knowledge Diamond. Practitioners do not need to take action regarding each single remark made in Figure 84 and Table 19. Nevertheless, they should make it explicit, if and when they do not take any action in regard to a particular topic.

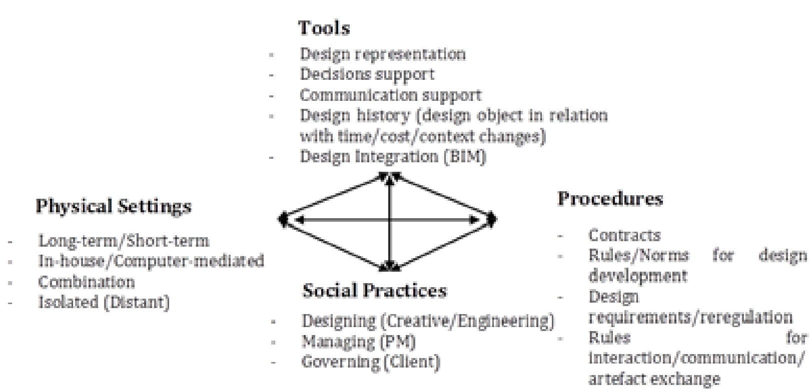

Figure 84
Examples of each dimension of the Knowledge Diamond Framework

Physical Settings: Long-term	
Spatial Properties	Select sufficient and flexible space that accommodates both focused and interaction spaces by taking team growth into the consideration.
Participation	Make sure that the designers play a role in designing their own work space.
(In)Formal Interaction Areas	Pay attention to the disciplinary work areas and change the actors' positions regularly so that each actor can benefit from the proximity of disciplines during the process. Pay extra attention to the informal, and formal interaction spaces and casual conversation places (once again the size, space and number of participants provide the design criteria) Plan and design casual spaces that can trigger shared routines and provide the potential to cultivate a shared culture within projects (i.e. lunchrooms, coffee corners facilitated with digital/hardcopy libraries, consider short-time interactive games for lunch breaks (table tennis etc.). Avoid the creation of private and difficult to access interaction corners within disciplinary islands
The Role of Division of Work	Use the division of work as a basis for designing the layout of disciplinary settings and pay attention to the danger of the division of work that could draw boundaries between the actors working in different groups. Rotate the designers so that they work in different divisions in order to enhance the possibility that they will gain a deeper understanding of the project.
Physical Settings: Short-term	
Frequency and Spatial Properties	Plan the meetings between managerial and design leaders, between design leaders and their crews explicitly and make sure that the decisions that matter to the design crews are conveyed adequately. Use different organizational settings for short-term physical settings; create these settings within the core organizational islands and enable different actors to observe each other's practices.
Participation	Allow different designers to participate in inter-disciplinary meetings and try to avoid the occurrences of 'project invisibles'.
Informal Interaction Areas	Stimulate informal interaction time and space within these settings.
The Role of Division of Work	Use the structure of the division of work while planning special 'interface' time for participants.
Steering & Content	Select a group who will be responsible for the management of short-term settings including the planning and management of the outcomes of physical settings. Rotate this task during each project phase in order to create space for peer pressure on actors to ensure systematic planning and organized settings, transferring decisions, and discussions through formal takeover processes Not only pre-determine the agenda and content of the meetings, but also encapsulate the discussions, which go further than agreed/dismissed design proposals, and stimulate each group to take their own minutes in their own style in order to bring together and correlate the discussions and actions.
Tools	
Pre-selection of new tools	Survey existing tools that can be used among other parties on a shared basis.
Current tools	Get feedback from the technical staff about the tools they currently use (for the purposes of designing, modelling interaction, repositories, etc.) and make sure that you are aware of the current trends in order to explore the potential of both existing and new tools .
Effects on the design methods	Anticipate the potential effects of tools in changing the current design methods in the project. Identify the possible changes and prepare actors for this recently changed methods, depending on the purpose and selection of the tools,

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Timing	Introduce the tools as early as possible in the design process. Explore the potential of the new tools while exploring new design concepts and elaborate on the new ideas. Have regular feedback sessions with the actors who are involved in the developing new tools in order to ensure that all the potential has been fulfilled and pay attention to the constraints the actors will face while experiencing the new tools. (Blend two learning processes together: explore what the project comprises as concepts ideas to understan the scope while also exploring the potentials of new tools, and become comfortable with design representa¬tion/interaction, etc.)
Evaluation	Periodically evaluate the commitment level (do the actors make use of newly develo-ped tools?)
Procedures	
Strategic Rationale	Develop a strategic rationale to make the strategic agreements and the consensuses reached explicit. Make sure that actors share their ambitions, that the initial design and implementation concepts are explicit, and that the weights of each dimension within KSS are shared. Get clients involved in KSS and develop an official addendum to the existing contract between client and design team organizations (in other words, develop a KSS-specific contract)
Operation Route	Develop an operational route that identifies and interrelates the operations of actors to be carried out regarding each dimension of a KSS; Plan the design and the organization of the physical settings throughout the design process; assign the roles and responsibilities regarding the design and changes of physical settings on a temporary basis (previously referred to as the creation of rotati-onal roles in different phases). Explicitly define the way that actors should interact in relationship to both the phy-sical settings and distant islands. This implies, defining which boundaries should be diminished and which should be preserved. Make the interaction network of actors explicitly clear to everyone involved by elaborating on the relationships of the team members schematically both within client-design team and between different design organizations. Make sure that the initial division of work is explicit and has been agreed upon by all parties involved (see Step 1).
Social Practices	
Organizations of KSS	Achieve consensus about the organizations participating in the selected KSS and clarify their expectations regarding KSS.
Drivers of Collabo-ration	Establish the collectively shared project drivers (objectives, project goals, professional pride), which should inform the implementation and create commitment among organizations.
Interaction	Define which groups should have a core or a supporting role in the knowledge sharing processes. Appoint people with a set of generally agreed responsibilities. Define who is responsible for communicating decisions and discussions. Stimulate people to assume their roles in different inter-organizational settings (both physical and distant). Find a mutual agreement regarding who uses which tools and how they are supposed to use them. Explore the use of organizational tools in a shared-platform in which project organizations can collaboratively work, perform distant interaction and record decisions.
Rules	Reflect upon the agreed shared goals, participants, expectations of organizations towards collaboration Define the frequency of group interactions or agree upon the irregularity and the way that irregularity should be managed.

Table 19

Recommendations for practitioners for setting basic rules and operational procedures

Step 4: Monitor social practices explicitly and regularly inform actors about each other's intentions and their performance designing a KSS

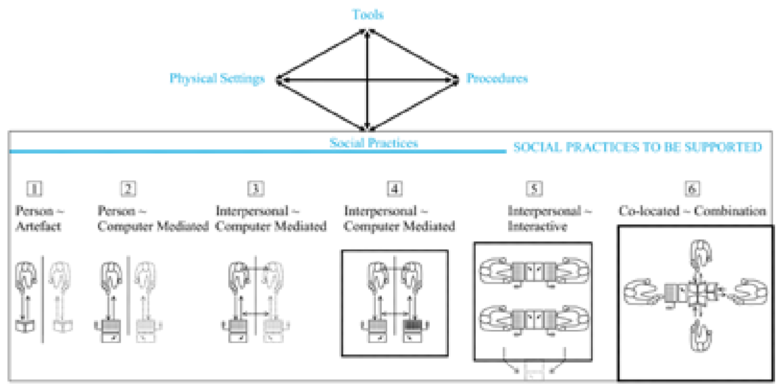

Figure 85

Examples of social practices in LCBPs in relationship to their different modes of working and interacting processes

Step four aims to equip the actors to perform successfully in the social practices that have been arranged to improve knowledge sharing within clearly demarcated physical and virtual territories, characterised by either strict or open boundaries, and well-defined degrees of freedom in which the actors operate. When successfully arranged, the social practices support and stimulate the actors in sharing their knowledge. In these social practices, actors are inclined to prevent misunderstandings regarding design solutions, ideas, roles, and responsibilities. Practitioners can use and adjust the components of Figure 85 in order to demonstrate the intended and (un)realized components of the selected KSS in relationship to the 'actors' performance in the social practices of the project.

Step 5: Evaluate KSS by reviewing whether the operations, which are carried out in the social practices, fulfil the original intentions (understanding both realized and unrealized components of the KSS), investigate, and then evaluate the emerging strategies.

Once the operations of each dimension in the Knowledge Diamond have been clarified, and once the actors are aware of both the necessity and the intentions of the selected KSS, the practitioners should evaluate whether their implementations fit within the social practices of the KSS. Practitioners should evaluate whether their intended KSS actually has created the intended type of Knowledge Sharing Environment (KSE). They can review the effects of their operations in the project by understanding and monitoring how social practices respond to the implementations. Figure 86 illustrates this step.

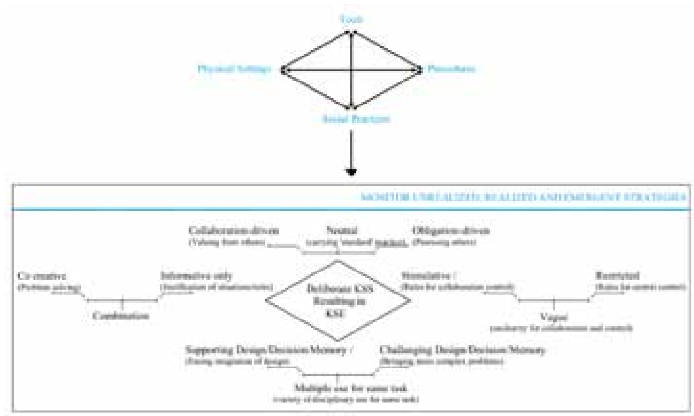

Figure 86

Monitoring whether the intended KSS is actually realized and reviewing the type of KSE created by the intended KSS

Practitioners can organize regular reviews or events as reflective environments. By means of these reflective environments, practitioners can re/assure the understanding of the selected KSS and re-direct the way that the KSS needs to be performed. This, in turn, leads to recommendations regarding the final Step 6.

Step 6: Reframe the KSS based upon the results of the evaluations of the intended KSS and the explorations of local practices' emergent strategies to strengthen the KSS

Practitioners should either embrace the emerging strategies as responses towards operations or develop new adequate practices in order to repair the missing aspects in the intended KSS. By recognizing and evaluating the emergent strategies, practitioners should adjust their intended KSS by revising their implementations and by analysing the unrealized components of the intended KSS. Figure 87 illustrates this step.

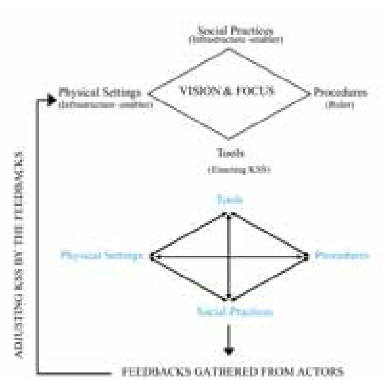

Figure 87

Cyclic loop between setting vision and operations of the selected KSS and adjusting the KSS through evaluating the responses of social practices towards implementations and synthesising emergent approaches with the intended KSS.

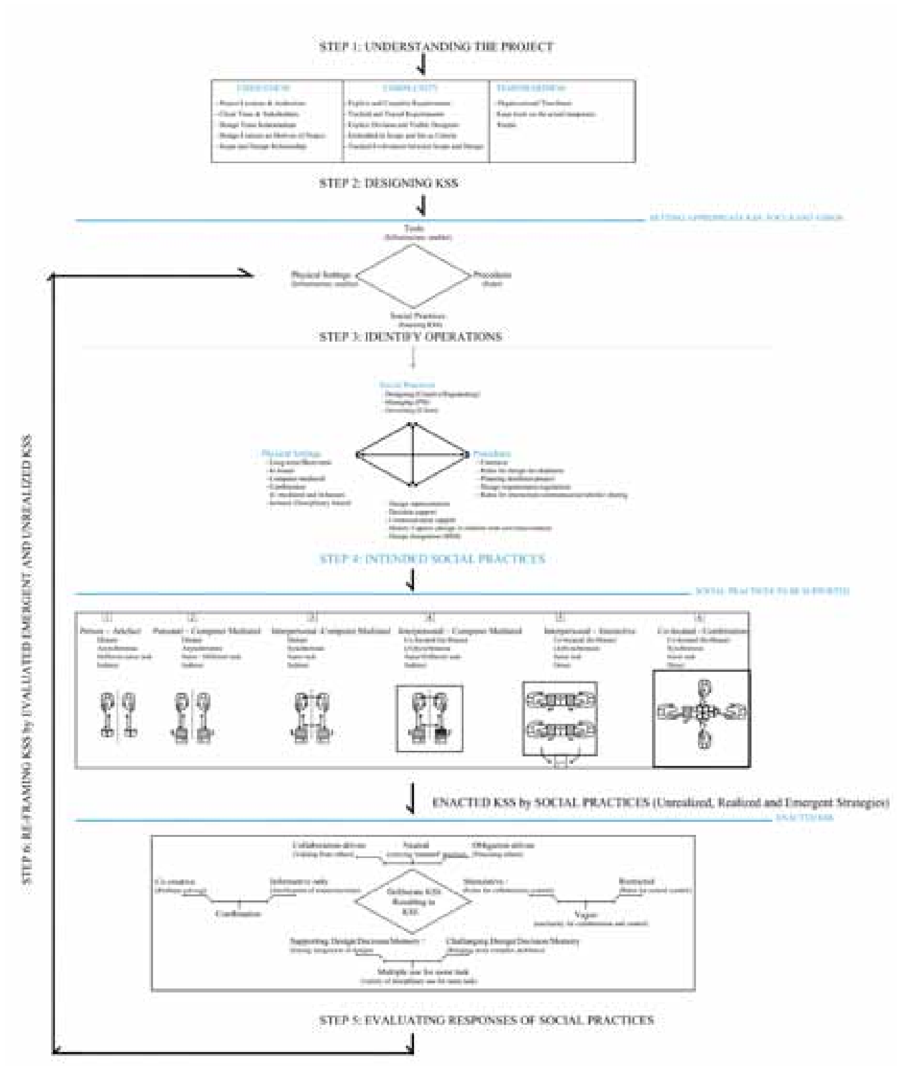

Figure 88

The steps to design and manage both deliberate and emergent KSSs in LCBPs

§ 6.7 The Reflection

In the reflection below, I will synthesize the findings of the empirical analysis, confirmation of the experts and the latter insights gained through the recent works of other researchers. Firstly, I reflect on generalization of the barriers to knowledge sharing and the suitability of LCBPs for investing KSS as an inter-organizational implementation. Secondly, I will reflect on the two cases and their different approaches as being either tool- or people-oriented

§ 6.7.1 Contribution to the Project Management Literature

In this study, I attempted to challenge the commonly held assumptions about characteristics of large complex building projects as unique, temporary, and complex through the empirical analysis of the two cases. As my analysis illustrated, these characteristics represent a misconception of project actors towards any inter-organizational effort, particularly for design and implementation efforts for knowledge sharing strategies.

Firstly, I attempted to portray the generic features of large complex building projects and emphasized that practitioners should not reinvent the wheel each time for each project. The point I tried to make was the impact of these characteristics is different than commonly thought and that most of the problems linked to limited knowledge sharingare also connected to the way the large complex building projects are perceived. This argument is similar to the point made by Flyvbjerg et al. (2011) that cost overruns between 50 to 100 % of the budget are common and overruns of more than 100% are 'not uncommon'. The conclusion of the uniqueness discussion is that while practitioners realize that each project is unique, they tend to overemphasize the uniqueness of each project rather than also see the commonalities between projects. This overemphasis was reflected on the social structure of these projects formed by organizational and individuals: projects are staffed on an ad hoc basis with little consideration for continuity between similar projects. This lack of continuity presents a danger for practitioners to overlook generic components of projects on that any knowledge sharing strategy can ground. In other words, there is a clear and obvious perception of practitioners on what makes each LCBP unique, but not on the generic features of their projects.

Secondly, I tried to pay extra attention to the difference between temporality of a project and temporarily of a LCBP that presented a long duration time for actors to work together. Due to their nature as projects with a certain start and end date, LCBPs are per definition temporary, which is often connotated as short-term. The expert panel provided additional insights on actual temporality of LCBPs, as several disciplines, advisors, or even the main design team members (i.e. architect, engineers, etc.) can temporarily affect LCBPs throughout their duration. In other words, LCBPs presents long-enough duration for practitioners but they are temporary to design and implement a KSS but these projects are also temporary for certain actors. In designing and implementing KSS, the temporality of project actors within the anticipated duration of a LCBP becomes crucial for practitioners.

Thirdly, I tried to reveal the real problem how complexity affects LCBPs. The changes of organisations, people, and decisions can become a major problem when the changes are not anticipated (when possible) and/or not handled by project actors. At this point, Axelrod et al. (2000)'s approach to the complexity becomes important to highlight (See Section 2.4.8). As the strategies for creating complex adaptive systems illustrate, practitioners who attempt to shape the behaviour of these complex systems should consider the variety of 'agents' in terms of ideas, backgrounds, and tool-mediation etc. Then these systems can bridge the gap that often sperates the humanistic and hard science approaches (Axelrod et al. 2000). Thus, it can be proposed that design teams of large complex building projects have a great potential to be a complex adaptive systems, and the holistic framework proposed in this thesis may be helpful to intentionally create such a complex adaptive systems.

Through the expert panel, it became clear that changes leading to fluid environment keeps challenge managing socially constructed concepts, as practitioners consider changes as 'the nature' of each LCBP. The conclusion for the complexity is that practitioners are able to manage the evolvement of social concepts that evolve implicitly and on a continual basis. A holistic approach that overarches capturing and managing changes becomes crucial but currently is lacking. Therefore, the holistic approach that embraced the Knowledge Diamond therefore is needed for LCBPs. The findings of this study and the recommendations for practitioners contribute to customizing project-specific approaches with regard to knowledge sharing. The results of this study regarding the characteristics of large complex building projects provide a analytical framework with which to examine projects when defining new project management methodologies. This links to the next contribution regarding the project management.

In this study, I attempted to fill the gap for managing knowledge sharing in large complex building projects through building a holistic framework that includes strategic concepts and the Knowledge Diamond framework. This framework contributes recoomendations for professionals involved in large complex building projects and enables them to design and implement knowledge sharing strategies within their project context and vision. The framework also enables these professionals to detect emergent knowledge sharing strategies in their projects.

In large complex building projects, there are strategies deriving from the need of the barriers to knowledge sharing that were identified previously. The expert panel helped to me to see the existence of these strategies and not only the two cases represented here. However, it became also clear that in large complex building projects, there is no distinction yet to define and distinguish whether a strategy is emergent or deliberate. In addition, practitioners do not consider these strategies as KSS. The expert panel presented that the holistic framework and the Knowledge Diamond are suitable frameworks to map both the type and the content of strategies in large complex building projects. If I can elaborate my reflections to the content of existing knowledge sharing strategies, I need to emphasize each aspect of the Knowledge Diamond.

This research revealed that tools present a great potential in dealing with knowledge sharing problems. They build technological infrastructure for knowledge sharing, as they offer the possibility to create virtual proximity to deal with complex changes in large complex building projects (i.e. changing design and criteria). However, there is still time, energy needed to invest in tools-use (to be aligned to the current large complex building projects) in order to exploit their full potential. This research made it evident that the physical settings does promote social processes that boost knowledge sharing processes, but not sufficient to promote people to share their knowledge in the large complex building projects. In other words, neither tools nor physical settings promote knowledge sharing in large complex building projects, if they stand alone. This is emphasized deliberately by Song et al. (2007) who states that the combination of co-location and computer-mediated environments (tool-supported) can nourish knowledge sharing. This is in line with the findings about social practices I observed in the two cases and illustrated in Section 5.4.6.

Currently, there is a knowledge gap between research and practice and this gap does result in repetitive yet not fully benefited strategies implemented by practitioners. The pace of practice does not accommodate the feedback loop between intended and realized strategies and therefore lacks of insights on the differences between what is intended and resulted. Although practitioners do adjust their strategies for future projects, they do not contribute what they learn in each strategy, not throughout the duration of LCBPs. Therefore, tools are not seen as miraculous solutions to all of the emerging problems and challenges in LCBPs.

Procedures create binding frameworks that regulate any activity that aims at knowledge sharing mechanisms (i.e. interactions, information exchange, physical settings, tools, etc.), but these frameworks cannot dictate the actors' behaviour regarding knowledge sharing. Styhre et al. (2010) treated these procedures as 'platforms' for knowledge sharing in their research, and they found that such procedural platforms serve as boundary object that prescribes a set of actions while leaving some space for individual initiatives for social interactions (Styhre et al. 2010). This supports the relevance and expected contribution of procedures aspect within the Knowledge Diamond to the knowledge sharing processes. Currently, I am involved in a project that develops a 'blueprint' for establishing regulations and agreements between project parties for BIM implementations (See Bektaş and Sebastian, 2013). This blueprint provides such a potential platform as Styhre et al. (2010) suggested.

Social practices involve in every operation within strategies. Social practices form knowledge sharing practices. In current LCBPs, project culture is established intuitively and on ad hoc basis, and actors engage in non-sharing behaviour at different levels (i.e. executive, managerial, and technical). With the expert panel, it became clear that Knowledge Diamond is useful to define and interconnect operations and has a potential to result in well-established sharing practices. Through explicit attention based on the holistic framework, that embeds the Knowledge Diamond, practitioners become able to know their existing social practices and build a deliberate KSS based on this knowledge. Furthermore, the Knowledge Diamond particularly represents a 'future-proof' framework that does not prescribe the way that existing tools are used (i.e. BIM and 3D models) but gives possibility to the practitioners to map recent trends in development of tools to be selected, and introduced for being part of a KSS in any future LCBP.

The theoretical ground established in this study in the form of the holistic framework together with insights drawn for practice contribute to the project management literature by bringing insights from the operations analysed at the work-floor of two cases.

§ 6.7.2 Contribution to the Theory Development

As one may have noticed in Chapter 1, in this study, I did not have any intention to deal with the measurement of the knowledge shared by the parties. I believe that such an intention would have led to a very different research project and outcome. I also do not propose that taking certain actions (implementing the possibilities stated above) would be a guarantee for establishing knowledge sharing processes among actors in LCBPs. By providing recommendations on the dimensions of the framework, I attempted to increase the likelihood of knowledge sharing among actors in LCBPs as well as increasing the awareness of the current design practices. Moreover, the mechanisms of knowledge sharing, the role of actors in these mechanisms, the necessity of basic rules and supporting tools have been made explicit.

This study treated boundary objects as socially constructed concepts. In line with Bresnen and Harrty (2010) who state that technological and social systems need to be understood as interdependent parts of a complex system yet there are also clear boundaries between technological and social systems, I want to clarify the approach I followed in this study. Even when the focus of discussions was on 'tools' or 'procedures' or ‘physical settings’, I tried to stress that each aspect is socially constructed in the discussions of ‘social practices’. While doing so, my aim was to show that there are different forms of boundary objects, which can be called either ‘technical’ or ‘episodic’ as defined by Ewenstein and Whyte (2009). In this study, the focus was on boundary objects produced in large complex building projects. Two types of boundary objects were found to be central: the design brief or program of requirements and the design as the final end product. These two objects are in the central arena of the actors yet can play a ‘chasing game’ with each other. The results of this study together with the recommendations shed light on what the main inter-dependent boundary objects are, how the project actors (fail to) manage their dependency and what the roles of boundary objects are (with a different degree of importance).

The research design was well suited for theory development based on two in-depth case analysis with the contribution to define inter-organizational knowledge sharing processes and theorize the discipline behaviours of people in project-based settings. Eisenhardt et al. (2007) notes that the rich data from in-depth case studies is a solid ground for building theories from case studies and studying more than one case provides stronger base for developing a theory. Therefore, this research provided a comparative and in-depth analysis based on rich data from the two cases. This analysis can be a basis for theory development, beyond the scope of this study. The holistic framework may form a fruitful basis form further theory development about knowledge sharing in project-based settings, and not only in the context of building projects.

§ 6.8 Limitations of the Research

One of the limitations of this research is the small number of case studied and the limited degree of generalization due to this small number. In this research, two case studies were selected and two different types of KSS were investigated. It would have been better to include more case studies that would represent different KSS based on the Knowledge Diamond framework (i.e. procedure-oriented, social practices oriented). Particularly, the inclusion of case studies in which the projects were realized through a DBFM contract - where a private party is responsible for design, construction, financing and maintenance (Yescombe et al. 2007; Hodge et al. 2010)- or cases based on the Build-Operate-Transfer (BOT) and Build-Own-Operate-Transfer (BOOT) contracts - as applied in the United States with different forms of funding (Miller et al. 2001; Herrala et al. 2011) could offer interesting results regarding the ‘Procedures’ dimension. Having more cases would also provide additional information and could lead to more insights regarding the legal responsibilities related to these integrated contracts and their impact on knowledge sharing. Such an analysis would help to develop the Knowledge Diamond framework further and it would contribute to the content of the legal obligations of actors in LCBPs regarding knowledge sharing practices.

The second limitation is related to the limited observation hours spent in the Architectural firm involved in the Case 2. During the data collection period, the majority of the observation hours were spent in the Engineering Firm 2's multi-disciplinary office, due to the limited access to the Architectural Firm. If it would have been possible to observe the current practices just as thoroughly as it had been in Case 1's architectural and engineering firms and Case 2's engineering firm, then a deeper understanding would have been possible regarding the characteristics of the design practice, which inhibited the creation of a shared project culture, which in turn might have facilitated knowledge sharing among the project actors.

The third limitation inherent to the nature of this type of research (Bosch-Rekveldt, 2011),) concerns the difficulty of operationalizing constructs during data collection and interpretation in an objective manner. These difficulties relate to the interpretation of the data and the iteration of the data interpretation. Although the findings were discussed with the supervisory team, they remain the result of a subjective interpretation and sensemaking process. The fact that I as the researcher was trained as an architect clearly helped me to make sense of what I was seeing, but it may have also coloured the findings.

The fourth limitation relates to the cultural differences between the projects. The two projects were conducted in different countries. Therefore, it is likely that there were also cultural differences in terms of management, communication, and business styles. In this study, I tried to be aware of these differences and describe them as detailed as possible in analysing the social practices. Furthermore, due to my personal background as an international researcher, I was more alert with respect to these cultural influences in the two project settings. One insight can be drawn in terms of socialization mechanisms and interactions within projects between design disciplines: individualistic cultures are likely to show less knowledge sharing than collective cultures, as interactions, communications and socialization mechanisms are more intensive at work environments in the latter. This intensity creates a different 'critical mass' to deal with particularly when a knowledge sharing strategy is implemented.

§ 6.9 Personal Notes and Further Research

When I started this study, one thing was always clear in my mind; I did not want to be involved in developing a new digital technology, since that was not my area of expertise. It was not because I did not believe in new technologies. On the contrary, I see a great supporting potential of such technologies for practitioners in LCBPs. My disinterest in contributing to new inventions for actors in LCBPs by new tools was due to the concept that I was interested in: knowledge sharing. I simply did not want to be confused by information or data sharing, although both were crucial in knowledge sharing and played a role in this study. Along the way, new trends and new technologies still 'blinked' to me for coming up with a digital solution that would start with an ideal of curing many problems, but which could end up targeting at a small niche which does not even deal with knowledge sharing at all. Instead of working on something that would not fulfil my ideal, I moved forward in exploring the dimensions of knowledge and mechanisms of knowledge sharing. In the end, I aimed at gaining an in-depth understanding of the way that actors are involved in such mechanisms and of their current practices in realizing LCBPs. Without understanding both topics, I believed any recommendation proposed in the final part of this study would have misfits. Therefore, in conversations with colleagues or friends, I referred to my method for this study as a 'gold-mining' process. One would call it 'hands-on'; others would refer to it as putting your hands into the 'mess of practice' and see what is good and what is poor when regarding knowledge sharing. Regardless of the name, in this study I aimed at exploring the current approaches of practitioners in LCBPs and contextualizing these efforts in a framework called the 'Knowledge Diamond'. I paid attention to the current practices by trying to cope with mismatches in the project environment and I explored the advantages and disadvantages of the current practices dealing with knowledge sharing mechanisms. I preferred to critically investigate the current design practices in order to provide an awareness of knowledge sharing strategies and their current efforts towards knowledge sharing. In doing so, I would learn from the experiences of those practitioners who had worked in LCBPs and these practitioners would learn from my reflections and the contextualization of their own efforts within a holistic framework. This was how I meant to conduct this study, analyzing the collected data, reporting the findings, and proposing recommendations for practice.

As one may have noticed in Chapter 1, in this study, I did not have any intention to deal with the measurement of the knowledge shared by the parties. I believe that such an intention would be directed at a very different research project and outcome. In this study, I did not bluntly propose that taking actions (implementing the possibilities stated above) surely provide knowledge sharing processes among actors in LCBPs. By providing recommendations on the dimensions, I attempted to increase the likelihood of knowledge sharing among actors in LCBPs as well as increasing the awareness of the current design practices. Moreover, the mechanisms of knowledge sharing, the role of actors in these mechanisms, the necessity of basic rules and supporting tools have been made explicit. The main conclusion is that none of the approaches can fully serve practitioners as a KSS, unless their visions are clear and shared and the implementations have been correlated regarding the dimensions of knowledge sharing.

While this study was conducted, many interesting themes and concepts popped up as options for further exploration. Below, I provide some examples of these themes for academics, students, or practitioners for further investigations.

As many PhD researchers, I have found myself on a journey through a 'sinus diagram'. I experienced both ups and downs; at one point, I thought I had no idea of what I was doing and then, suddenly I felt very confident and clear. My last five and a half years have been like this, except the lucky majority of PhDs. In this process from unknown to known (and vice versa), I have been where I know exactly what I am doing and where I did doubt that I do not know enough to realize this work. These two feelings represented two sharp edges in my overall research journey. I progressed through the confidence after digesting my research themes, and learned more about my field through my constant doubts. These changing feelings made me select the themes I wanted to explore further, the themes I needed to leave aside, even though they made me feel very enthusiastic. The themes I dropped along the way opened new 'windows' for further research interests. These themes made me aware of the fact that there is still a great deal to learn, to doubt, and to research. Below, I draw some of the themes on which I personally would like to conduct further research.

The first theme that I would like to research further refers to designing scenarios of KSS, which could be implemented in real-life projects. This subject stipulates action research as it would require working closely with the practitioners and reformulating the research through the feedback of actors participating in KSS. In this possible research, evaluating KSS becomes crucial. This evaluation would consider the questions of whether implemented KSS eases managing design changes, building understanding among actors, enhancing either social and remote interactions, etc. Exploring these scenarios includes the questions as to what extent intended and designed KSS have positively influenced the project objectives. In other words, I have become curious about the actual results of a designed and implemented KSS based on the Knowledge Diamond in real-life LCBPs.

The second theme becomes greatly linked with the first one. In this study, I focused on 'large complex building projects' and I excluded infrastructure or large product development projects. Therefore, another question to be investigated would be whether the Knowledge Diamond framework would also work within different projects. This is not solely about the differences in the scales of the projects (although this would be an interesting subject to know, too), the question would be whether the framework proposed in this study is also suitable for other large settings such as large product development projects, or within different businesses such as the cinema industry.

The third theme has partially been investigated in this study; the management of both client and design teams' activities through their main boundary objects. This theme requires the correlation of two main objects as the scope of the client scope and the overall design solution. Therefore, the third theme becomes finding solutions that manage project brief and the design object itself. In this study, I examined the current problems that occur due to too rigid/loose clients' briefs and a design object that has been elaborated by design teams intuitively towards changes of briefs over time. This raises the question of "what would be the most suitable management solution that explicitly targets the main design object of both the client and the design teams and their involvement in projects. This subject requires a retrospective approach in order to detect what extent changes and revisions in both objects are made explicit (i.e. through meetings, official requests, change orders, phase closure documents, e-mails, etc.) and where the two objects started not to match.

The last subject I propose has been based once again on the Knowledge Diamond framework. This time I propose a theme using the framework to investigate alternative KSS in other real-life projects. In other words, I propose using the Knowledge Diamond as an exploration tool to find out other approaches that deal with project challenges and knowledge sharing in LCBPs. One example, which can be given, is the integrated contracts. It becomes interesting to discuss to what extent integrated contracts represented a KSS for LCBPs by focusing on procedures dimension. This potential research would explore the efforts of actors in the selected projects regarding physical settings, tools and social practices as well as the procedures. This potential research would reveal to what extent new integrated contracts results in commitment of design team organizations for collaboration in design process. This potential research would provide an outcome in answer to what would be the legal framework that elaborates and defines a KSS within large complex building projects. What would be the 'integrated' contract package that is to be inserted into the new forms of contracts (as proposed better practices such as DB, DBFMO, etc.)?

The last theme refers to exploiting digital technologies and investigating the extent of current tools in using a KSS. The subject to be explored is to what extent a shared design tool is built through using current KMS/Blackboards/Repositories of design team organizations so that practitioners can design and implement a KSS around this shared-tool.

More research subjects could be cultivated through elaborating and interpreting the dimensions of the knowledge diagram or interpreting the framework for alternative KSS models. Exploring any of the themes proposed above would contribute greatly to both practitioners and academics who are interested in the management of knowledge, knowledge sharing, building project culture, conflict management, design management, information management, and cross-industry learning themes. Any of the subjects would fill the gap in knowledge sharing strategies in inter-organizational level (and inter-disciplinary) on a project-basis including the recommendations for the practice presented in this study.

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Glossary

Information

In this research, information is treated as a basis for knowledge. It is produced by either individuals or groups and it embeds to a certain degree, explicit knowledge. Once information has been interpreted, knowledge is (re)generated. Through interpreting the information and relating to the existing personal repositories, theoretically knowledge can be accumulated.

Knowledge

In this study, knowledge is perceived as residing both in individuals (as they are the representative of their organizations) and in organizational routines (as the routines shape and reframe the knowledge of individuals). Knowledge becomes meaningful and useful when it is applied to work, a task, or a problem that organizations need to tackle. Knowledge can be seen as a personal repository, with its development being shaped by the different levels of personal experience, education, culture, or personality, although these do not form the core of this study.

Tacit Knowledge

In this study, tacit knowledge is perceived as an ‘intelligence cushion’ that holds new information, transforms it to a new knowledge, and grows in every step of a knowledge process. It is highly personal but has a collective dimension within organizations. Tacit knowledge is personal and is built through experience, skills training, and education, which in turn are influenced by talent and skills. The organizational dimension comprises unwritten rules of work practice, socially shared rules that are often not very explicit. This knowledge can be obtained by participating in the work practice and/or first observing then imitating.

Explicit Knowledge

Explicit knowledge is called complementary knowledge that can be codified and one can extract meaning from the “codes” (Anumba et al. 2005). It can be codified and transferred from individual memory and recorded through spoken and written words, diagrams and equations. Others may then reproduce this knowledge once the code becomes available.). Through explicit knowledge, people make their presence felt in social and professional environments: because it is ‘communicable’.

Knowledge Sharing

Knowledge sharing is a process of exchanging skills, experience, and understanding among people. It is a multitude of processes taking place directly without language (socialization) and with language (externalization). In this research, two types of knowledge sharing processes have become evident: 1) Indirect knowledge sharing through tools and artefacts, 2) Direct knowledge sharing through social interaction.

Knowledge sharing through tools and artefacts can be seen as a remote process, which occurs when sharing captured, codified, and stored knowledge. This process overlaps with information sharing due to both explicit and tacit knowledge to be interpreted. Knowledge sharing as a social process occurs through language. By using language, actors share their knowledge by communicating, interacting, and validating their understanding.

Knowledge Sharing Strategies (KSS)

In this research, Knowledge sharing strategies (KSS) refer to sets of implementations planned to facilitate externalization and socialization processes in and between actors who conduct and evolve their organizational practices, who improve access to information, who ease the communication between the actors, and who encourage participation in learning which is sustained by knowledge sharing. In the design teams of LCBPs, KSS are planned approaches used to tackle knowledge sharing processes among different organizations in both remote and proximate manners. These approaches should have technological, social, technological, and procedural dimensions.

Knowledge Sharing Environment (KSE)

KSEs are both virtual (tool-supported) or physical (co-located) environments accommodating boundary objects (both informal artefacts and formal design precedents), people (having both tacit and explicit knowledge), interaction for knowledge sharing (observation/ imitation and socialization/confirmation). KSEs are physical or virtual settings, which facilitate project actors to exchange their insights, understandings, and perspectives so that the actors reinforce their knowledge about the project's course, and so they are aware of the other actors' agendas and objectives.

Design Team and Design Crew

Design team is a cross-functional setting that is formed by organizations involved in projects in order to resolve the tasks that cannot be dealt with by one discipline and the people. It consists of representatives of the organizations involved to pursue the organizational objectives and to fulfil the tasks as defined by the clients. Design team has a complex nature in terms of their varied interests, the division of labour, and their boundaries between the work units. Design team comprise individuals (single representatives of their organizations) and/or design crews whose professions consist of various disciplines. These disciplines may belong to different organizations that have been contractually bound to one another.

Design Team Members (Actors/People/Individuals)

Design team members represent the knowledge actors who process and produce information, who generate and share knowledge, and who take and reflect on actions in the design environment. They take part in projects as representatives of their knowledge domain. They process and reproduce data and information, and provide other members of organizations with this same data. They convey their work routines, observe the similar/different routines, reflect, and re-frame their environments. They form the knowledge sharing practices through their actions. They are clients, advisors, project managers, architects, construction managers, design, and engineering group members, specialists or general contractors and they are all knowledge actors.

Boundary and Boundary Crossing

Boundaries are non-visible borders that define the territories of project actors in a project environment. They are drawn by functional specialism, discipline types or contractual relationships which give legal, physical, and social character to the boundaries. These boundaries are crossed by individuals and realized by different mechanisms such as exchanging boundary objects (i.e. drawings, personal conversations (Fong 2003), reports, documents that particular project actors provide, and e-mails. Boundary crossing refers to a process where project actors exchange their both information and data (i.e. deliverables) they produce. Boundary crossing plays an important role in knowledge sharing but does not guarantee knowledge sharing.

Summary

The construction industry is a project-based sector with a myriad of actors such as architects, construction companies, consultants, producers of building materials (Anumba et al., 2005). The interaction between the project partners is often quite limited, which leads to insufficient knowledge sharing during the project and knowledge being unavailable for reuse (Fruchter et al. 2002). The result can be a considerable amount of extra work, delays and cost overruns. Design outcomes that are supposed to function as boundary objects across different disciplines can lead to misinterpretation of requirements, project content and objectives. In this research, knowledge is seen as resulting from social interactions; knowledge resides in communities and it is generated through social relationships (Wenger 1998, Olsson et al. 2008). Knowledge is often tacit, intangible and context-dependent and it is articulated in the changing responsibilities, roles, attitudes and values that are present in the work environment (Bresnen et al., 2003). In a project environment, knowledge enables individuals to solve problems, take decisions, and apply these decisions to actions. In order to achieve a shared understanding and minimize the misunderstanding and misinterpretations among project actors, it is necessary to share knowledge (Fong 2003).

Sharing knowledge is particularly crucial in large complex building projects (LCBPs) in order to accelerate the building process, improve architectural quality and prevent mistakes or undesirable results. However, knowledge sharing is often hampered through professional or organizational boundaries or contractual concerns. When knowledge is seen as an organizational asset, there is little willingness among project organizations to share their knowledge. Individual people may recognize the need to promote knowledge sharing throughout the project, but typically there is no deliberate strategy agreed by all project partners to address knowledge sharing.

In the literature, two main approaches on knowledge sharing can be distinguished, an object or content -oriented perspective and a community-oriented perspective. In the object perspective, technology is seen as a medium to store and share knowledge. The limitations of this perspective are that social processes and tacit knowledge are not adequately supported and there has generally been a slow adoption of such technology in design practices. The community perspective prevents these problems by allowing for the natural and informal formation of communities, however, communities can become largely independent and unconnected, which makes it more difficult to entice them towards a certain strategic direction. Since both approaches have their limitations, this thesis proposes a holistic framework for knowledge sharing in LCBPs drawing on concepts by Mintzberg (1973) and Activity Theory. Mintzberg's concepts are used to discuss the type of implementation (top-down, bottom-up), and the origin of the strategies (deliberate/emergent/(un)realized). For analysing the content and effect of

each strategy, concepts from Activity Theory (tools, subject, object, rules, community, and division of labour) are used. The proposed model, the Knowledge Diamond, consists of four dimensions for analysing and designing knowledge sharing strategies for LCBPs. Three of these were inspired by Activity Theory, namely tools, procedures, and social practices, while a fourth emerged as a crucial dimension in this thesis: physical settings.

This framework was used to examine knowledge sharing strategies in a comparative analysis of two large complex building projects. Based on rich data from observations, documents and interview, the origins, the development and the effect of both forms of knowledge sharing environments are investigated. The first part of the analysis sheds new light on the possibilities of knowledge sharing in large complex building project. The unique, temporary, and complex nature of such projects has often been reported as a potential barrier to investing knowledge sharing. However, this analysis highlighted that the while the location is unique, the underlying challenges are typically not, and although projects are per definition temporary, these large, complex projects often last for a decade. Investing in knowledge sharing is therefore possible and worth the effort, and with respect to complexity more needed than those involved are aware of.

In the second part of the empirical data analysis, the knowledge sharing strategies inuse in the two cases were examined. The first case represents a people-oriented approach using collocated open plan offices for the entire design team; the second case represents a tool-oriented approach drawing on a Building Information Model (BIM). The co-located offices provided the physical setting for knowledge sharing, but it not planned as a conscious strategy and so was mainly regarded as sharing the same office floor and was not used to its full potential. Physical boundaries remained between sub-teams and interaction was restricted to the level of project managers. In the second case, the implementation of a BIM represented a bottom-up and emergent strategy that embraced digital technologies for specific problems. The analysis showed that there was limited understanding about requirements and implication of changes in the design processes. Introduced through a bottom-up emergent strategy without commitment from all project partners, it was not possible to utilize the potential benefits of a BIM system for the overall design team. The analysis also revealed that what practitioners referred to as a BIM, was not a true BIM implementation, thereby indicating that digital concepts are still not completely clear in practice.

This comparative analysis of two cases led to several conclusions:

- Irrespective of whether a tool or people-oriented approach is used, there will be emerging strategies with which people try to address problems caused by limited knowledge sharing.

- The physical setting can play a major role in supporting interaction. Designers and managers will make intentional or spontaneous use of the possibilities that their physical setting affords, even though tools are available that can facilitate distributed work. Thus, tool implementations do not make physical settings obsolete.

- Tools provide a technological infrastructure such as creating virtual proximity, handling design and criteria changes, enhancing design representation, or dealing with changes in personnel. However, there is no magic want that cures all problems and challenges of LCBPs.

- Procedures refer to formal and informal rules about knowledge sharing. Such rules are important means of creating shared expectations and information exchange, however, procedures can only guide but not dictate the actual behaviour of actors in regard to knowledge sharing.

- Social practices form the social infrastructure that enables and facilitates knowledge sharing through the physical setting, tools, and procedures. However, if the project culture has emerged intuitively, these practices may involve rather limited sharing behaviour at various levels (i.e. executive, managerial, and technical).

Through my research and recommendations, I have attempted to offer fresh insights to practitioners about the value and necessity of knowledge sharing in large complex building projects. The framework of the Knowledge Diamond is not intended as a magic cure, but it can serve as a guideline for enhancing knowledge sharing by paying explicit attention to all four dimensions and taking advantages of new technologies such as BIM and 3D models. Although the insights of this research are based on only two cases, the conclusions were confirmed by a panel of experts who confirmed similarities with their own experience.

This study also contributed to the literature on knowledge sharing and project management. The Knowledge Diamond can help to conceptualise knowledge sharing at both the inter-organizational and cross-disciplinary level. It can also form the basis for further theory development about work in project-based settings and help to define new project management methodologies.

Samenvatting

De bouwsector is een projectmatig werkende bedrijfstak met veel verschillende partijen zoals architecten, bouwbedrijven, consultants en producenten van bouwmaterialen (Anumba et al, 2005). De interactie tussen de project partners is vaak beperkt, met als gevolg dat de tijdens een project verzamelde kennis verloren gaat en niet beschikbaar is voor hergebruik (Fruchter et al. 2002). Gewoonlijk leidt dit tot een aanzienlijke hoeveelheid extra werk, vertragingen en budgettaire problemen. De verkeerde interpretatie van deelresultaten (de resultaten van verschillende disciplines, zoals tekeningen, rapporten, en onderzoeken) kan een negatieve invloed hebben op het project en de doelstellingen van de betrokken partijen. In dit onderzoek wordt kennis gezien als een het resultaat van sociale interactie (Wenger 1998, Olsson et al. 2008). Kennis is vaak onbewust of impliciet, immaterieel en contextafhankelijk.

In een projectomgeving stelt kennis mensen in staat om problemen op te lossen, beslissingen te nemen en deze beslissingen om te zetten in acties. Het is noodzakelijk kennis op de juiste manier binnen het project met elkaar te delen zodat misverstanden worden voorkomen (Fong 2003).

Kennisdeling is zeker van cruciaal belang voor grote en complexe bouwprojecten om het bouwproces te kunnen versnellen, de bouwkundige kwaliteit te verbeteren en fouten te voorkomen. Bij het delen van kennis in grote, complexe bouwprojecten is het noodzakelijk dat ontwerpteams functionele, organisatorische en contractuele grenzen overbruggen. Organisatorische grenzen maken het plannen en faciliteren van kennisdeling complexer en problematischer. Dat komt omdat kennis als machtsinstrument wordt beschouwd en er bij afzonderlijke projectpartners weinig bereidheid is om hun kennis te delen. Ondanks deze geringe bereidheid van organisaties kennis te delen, is er juist bij de individuele projectmedewerkers behoefte om kennis te delen. Een gezamenlijke, door alle projectpartners gedragen strategie om kennisdeling te bevorderen ontbreekt echter.

Kennisdeling wordt in dit onderzoek vanuit twee gezichtspunten benaderd: de objectgerichte- en de mensgerichte benadering. Bij de objectgerichte benadering (ook wel middelengerichte benadering genoemd) wordt technologie gezien als een middel voor het opslaan en delen van kennis. Algemeen is men van mening dat deze benadering zijn tekortkomingen heeft op het sociale vlak. Het omgaan met onbewuste en impliciete kennis is bij deze benadering niet mogelijk en de implementatie van dergelijke technologie in de ontwerppraktijk is tot op heden vrij beperkt. Bij de mensgerichte benadering echter, staat de competentie van mensen centraal om zowel met expliciete, als impliciete en onbewuste kennis om te kunnen gaan. Kennisdeling vindt daarbij plaats door interactie tussen mensen. Als voorbeeld van een kennisdelingsstrategie met een mensgerichte benadering worden Communities of Practice (CoP) veelal genoemd.

Omdat beide benaderingen specifieke beperkingen hebben, is in dit onderzoek een holistisch raamwerk ontwikkeld waarbij de modellen over strategievorming van Mintzberg (1973) en de activity-theory van Engeström (1999) zijn samengevoegd. Het model van Mintzberg is gebruikt om het type implementatie te kunnen beschrijven (top-down, bottom-up) en de aard van de gekozen strategieën. Voor het analyseren van de inhoud en het effect van iedere strategie zijn onderdelen van de Activity Theory gebruikt. Het resultaat van deze samenvoeging heeft de naam "kennisdiamant" gekregen. De kennisdiamant bestaat uit vier dimensies die gebruikt kunnen worden bij de analyse van kennisdelingsstrategieën voor grote, complexe bouwprojecten. Drie dimensies zijn afgeleid uit de Activity Theory, namelijk middelen, procedures en de sociale context. De vierde dimensie, de fysieke omgeving, ontstond als cruciale dimensie tijdens dit onderzoek.

Het raamwerk, de kennisdiamant, is gebruikt voor de gedetailleerde analyse van twee projecten. Met behulp van gegevens verkregen uit observaties, documenten en interviews zijn de ontwikkeling en implementatie van kennisdeling in de projecten geanalyseerd. Door de mogelijkheden en tekortkomingen van beide praktijkprojecten te bestuderen, is veel inzicht verworven in de mogelijkheden van kennisdeling binnen grote en complexe bouwprojecten. Deze inzichten werpen een nieuw licht op de in de literatuur beschreven eigenschappen van grote, complexe bouwprojecten. De unieke, tijdelijke en complexe aard van projecten wordt in de literatuur vaak beschreven als barrière voor het implementeren van strategieën voor kennisdeling. De analyse in dit onderzoek heeft echter de conclusie opgeleverd dat het unieke en complexe karakter juist de noodzaak voor kennisdeling benadrukken. Tijdelijkheid blijkt in het geval van grote complexe projecten geen rol te spelen, immers dergelijke projecten hebben een doorlooptijd van jaren.

In het tweede deel van de analyse zijn de kennisdelingsstrategiën van de beide casussen in detail geanalyseerd. Het eerste project is een voorbeeld van de mensgerichte aanpak. In het project wordt co-location toegepast (het samenbrengen van ontwerpdisciplines op één vaste locatie in een open kantoorconcept). De tweede casus was een project met een middelengeoriënteerde benadering waarbij een Bouw Informatie Model (BIM) is toegepast.

Het samenbrengen van alle ontwerpdisciplines in één open kantoor leverde de juiste fysieke omgeving op om kennisdeling mogelijk te maken. Het bleek echter geen geplande en bewuste strategie te zijn, waardoor de projectmedewerkers dit vooral beschouwden als het delen van hetzelfde kantoor, zonder daadwerkelijk kennis te delen. Fysieke grenzen tussen de verschillende disciplines bleven aanwezig en er was alleen interactie op het niveau van de projectleiders. Tijdens de analyse van de tweede case, met de implementatie van BIM, werd een strategie ontdekt die tijdens het project spontaan was ontstaan. Daarbij bleek dat er geen rekening gehouden was met de eisen van en de benodigde veranderingen in het ontwerpproces. De strategie was bottom-up ontstaan, zonder dat daarvoor draagvlak bij alle projectpartners was. Het gevolg was dat de potentiële mogelijkheden van de toepassing van BIM voor het gehele ontwerpteam niet ten volle benut konden worden.

De analyse van de twee casussen heeft tot verschillende conclusies geleid:

- ongeacht het feit of er een middelen- of mensgeoriënteerde benadering is gebruikt, zijn er altijd niet-geplande, spontane acties van mensen die proberen problemen op te lossen die veroorzaakt zijn door een gebrekkige kennisdeling

- De fysieke omgeving kan een belangrijke rol spelen bij het bevorderen van interactie. Ontwerpers en managers maken opzettelijk of spontaan gebruik van de mogelijkheden die de fysieke omgeving biedt, ongeacht de overige beschikbare middelen. Met andere woorden: (ICT) middelen maken de fysieke omgeving niet overbodig.

- Middelen leveren een technologische infrastructuur waardoor teamleden op afstand kunnen samenwerken en bijvoorbeeld ontwerpwijzigingen efficiënt kunnen afstemmen. Er bestaat geen wondermiddel om alle problemen en uitdagingen op het gebied van kennisdeling op te lossen.

- Procedures verwijzen naar formele en informele kaders die activiteiten reguleren, gericht op kennisdeling. Deze kaders zijn een belangrijk hulpmiddel om gezamenlijke verwachtingen te creëren. Deze kaders kunnen het gedrag van deelnemers met betrekking tot kennisdeling echter niet voorschrijven.

- De sociale context is een factor die kennisdeling moet bevorderen en faciliteren. Als de projectcultuur eenmaal intuïtief is gevestigd, brengt dit gedrag met zich mee waarbij kennis op de verschillende niveaus niet wordt gedeeld (uitvoerend, bestuurlijk en technisch).

Met de onderzoeksresultaten en aanbevelingen is geprobeerd de praktijk nieuwe inzichten te bieden zodat zij zich bewuster wordt van de mogelijkheden voor kennisdeling. Daarnaast zijn manieren beschreven die als leidraad dienen voor het implementeren van een kennisdelingsstrategie zodat men in de praktijk geneigd zal zijn daadwerkelijk kennis te delen. Het raamwerk van de kennisdiamant is niet bedoeld als wondermiddel, maar het kan helpen als richtlijn bij het bevorderen van kennisdeling, waarbij expliciet aandacht wordt besteed aan alle vier dimensies.

Hoewel de inzichten uit dit onderzoek gebaseerd zijn op de analyse van twee projecten, zijn de conclusies bevestigd door een groep van experts. De experts hebben het onderzoek voorzien van soortgelijke voorbeelden uit hun eigen ervaring en ze benadrukken ook dat een kennisdelingsstrategie niet zonder meer kan worden ontworpen en geïmplementeerd vanuit slechts één gezichtspunt.

Door het leggen van de focus op de interorganisatorische en discipline overstijgende aspecten van kennisdeling in bouwprojecten, heeft deze studie een belangrijk hiaat in de wetenschappelijke literatuur over kennisdeling en projectmanagement opgevuld.

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Lastly Dennis, my husband to be, I think someone should give you the highest degree of patience. The understanding, love, and care that you provided to me made simply my life happier. You always had confidence in me. In all the uncertain moments of a PhD life, your stability was the treasure. I truly know, even a happier life is waiting for us.

Curriculum Vitae

After the graduation in architecture, Esra Bektaş contributed to both education and architectural practice. Until 2003, she worked for designing of several housing development, office, and retail projects for several architectural firms. Besides, she involved in several project proposals for architectural design competitions. In 2003, she enrolled in a master course at the Erasmus University of Rotterdam in 2003 to gain more perspectives on the management side of both architecture and planning which is one of the problematic fields for architects. In that course, she studied in two countries, the Netherlands and Sweden, and obtained the Master of Science degree in December 2004 with a thesis that touches on a shortcoming of Turkey; Disaster Management. Following the graduation, she returned to her home country, in order to apply her gained theoretical knowledge and international experiences. She worked for a private sector company; MNG Group of Companies and mostly worked on the design of medium and large-scale building projects in both national and international levels. She started to develop special interest on large scale building projects and the processes required to achieve them. From September 2007 until September 2012, she worked on her PhD Project; "Knowledge Sharing Strategies for Large Complex Building Projects." She conducted her research in the Delft University of Technology together with Prof. dr. Ir. Hans Wamelink, Prof. dr. Kristina Lauche and Dr. John Heintz. Since September 2012, she has been working as a scientific researcher for TNO Netherlands Organisation for Applied Scientific Research within the 'BouwICT' [Building ICT] team. She has been involved in various European Union projects with differing responsibilities.