CHALMERS
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Concurrent Engineering in Construction Projects

Lesson learned from the oil and gas industry

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

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Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Concurrent Engineering (CE) is a holistic approach to the design, development and production of a product. This approach is intended to streamline the design process of a product through integration of the different stakeholders into the design phase and enhancement of information exchange between them. Other industry sectors such as the oil and gas industry have been benefiting significantly by implementing CE. The aim of this study is thereby to investigate and compare the working method of an oil and gas organization with a construction organization to find out potential benefits of CE in the construction industry and how it successfully can be implemented within a construction organization. The focus of this study is the design phase of the project and is carried out by interviews with people involved in the design phase as well as people highly involved with information systems and management control systems. Due to uniqueness of each project this study could not confirm that the project cost or time have been reduced but by implementing CE the oil and gas organization has managed to streamline the design phase by cutting the unnecessary waiting time between decision and action, decrease error of the design and increase quality of the projects. There are many similarities between oil and gas projects and construction projects and the construction industry could gain similar benefits by implementing CE. This study concludes that a successful implementation of CE requires inter alia full support from senior management, change agents, pilot projects and team buildings. The study recommends construction organizations to adjust CE so it fits the organization's needs and conditions. Furthermore, BIM meetings are suggested to be a suitable platform for developing into CE work sessions.

Key words: Concurrent Engineering, CE, oil and gas, information and communication system, BIM, implementation, change agents, pilot project, project leader, facilitator.

Integrerad Produktframtagning i byggprojekt
Erfarenhet från olja- och gasindustrin

Examensarbete inom mastersprogrammet Design and Construction Project Management

FARHAD SAFDARI

Institutionen för arkitektur och samhällsbyggnadsteknik
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Chalmers tekniska högskola

SAMMANFATTNING

Integrerad Produktframtagning (IP) är ett holistiskt tillvägagångssätt för design, utveckling och produktion av en produkt. Detta tillvägagångssätt syftar till att effektivisera designfasen av en produkt genom integration av de olika intressenterna i designfasen och förbättring av informationsutbytet mellan dem. Andra industrisektorer, som olje- och gasindustrin, har haft stor nytta av IP-implementering. Syftet med denna studie är att undersöka och jämföra ett olje- och gasföretag med ett byggföretag, i relation till deras arbetssätt, för att ta reda på eventuella fördelar med IP inom byggbranschen och hur det framgångsrikt kan implementeras inom ett byggföretag. Inriktningen för denna studie är projektets designskede och genomförs genom intervjuer med personer som är involverade i designfasen samt personer som är djupt involverade i informationssystem och styrsystem. På grund av den unika karaktären hos varje projekt kunde denna studie inte bekräfta att projektkostnaden eller tiden har minskats, men genom att implementera IP har olje- och gasorganisationen lyckats effektivisera designskedet genom att minska den onödiga väntetiden mellan beslut och åtgärder, minska designfel och öka produktkvaliteten. Det finns många likheter mellan ett olje- och gasprojekt och ett byggprojekt och därmed kan byggindustrin få liknande fördelar genom att implementera IP. Denna studie drar slutsatsen att en framgångsrik implementering av IP kräver bland annat fullt stöd från ledningen, förändringsagenter, pilotprojekt och teambuilding. Studien rekommenderar byggnadsorganisationer att anpassa IP så att det passar organisationens behov och förutsättningar. Vidare föreslås BIM-möten som en lämplig plattform för att utvecklas till IP-arbetssessioner.

Nyckelord: Integrerad Produktframtagning, IP, olja och gas, information- och kommunikationssystem, BIM, implementering, förändringsagenter, pilotprojekt, projektledare, facilitator.

Contents

Preface

This research has been executed in fulfilment of the Master's Programme Design and Construction Project Management carried out at the Department of Civil and Environmental Engineering, division of Construction Management at Chalmers University of Technology.

I would like to thank everyone who somehow has contributed to this study. I share my gratitude and appreciation to the organizations involved in this study. Thanks for giving me the privilege to be part of your organization during this research. Special thanks to all interviewees for your time and for sharing your knowledge and experiences with me.

My special thanks go to Petra Bosch-Sijtsema my main supervisor at Chalmers University of Technology. Thank you for your tireless effort in guiding and supervising me through this study and thank you for giving me the opportunity to fulfill this thesis.

Göteborg April 2018

Farhad Safdari

1 Introduction

1.1 Background

According to an investigation by Swedish Government Official Reports rework makes up to 5-15 percent of the total production cost in Sweden (Byggkommittén, 2005). When this also Includes other non-value adding activities such as unnecessary transports, waiting time, bad logistic, shrinkage, incorrect planning and other wastes, the number goes up to 30 percent. Furthermore, in the same report it is mentioned that the operation and maintenance cost usually exceed the planned amount because of errors during the design and construction phase. The construction sector is Sweden's second largest business sector with a turnover up to 450 billion SEK (Byggkommittén, 2007). With this huge amount of money at stake there is a lot to gain with better efficiency in the construction industry.

One of the most important phases of a construction project is the design phase, because 80% of the life-cycle economic and environmental costs associated with buildings are determined during this phase (Bogenstätter, 2000). The decisions made during the early design stage have a huge impact on the entire project life-cycle and decrease in influence as the design matures (Paulson, 1976). So, improving the design and the design processes are the most important and efficient way for improvement of the entire project life-cycle economy and environmental costs.

Concurrent Engineering, CE is a work methodology that is intended to streamline the design process of the construction projects though integration of the different disciplines into the design phase and enhancement of information exchange between them (Jie, Shouke & Zhuobin, 2010). CE was introduced for improving quality of the design, decrease product development time, decrease manufacturing cost, and to reduce the amount of rework (Bertrend et al., 1988), which all directly reflect the challenges of the construction industry.

CE is a management, engineering and business approach that relies on concurrency of the design activities and integration of product information for aligning the different work processes (Anumba, Cutting-Decelle and Kamara, 2007). This information exchange between different disciplines and integration of all project life-cycle information could be enhanced by a methodology called Building Information Modelling. BIM is an information system methodology that preaches for smarter management of project related information (Gu and London, 2010).

Other industry sectors, such as the automotive industry (Crowley, 1998), aerospace industry (Flager & Haymaker, 2009) and oil- and gas industry (Abbas & Manarvi, 2011) are benefiting significantly from the adaptation of Concurrent Engineering and enhanced information systems and so why can't the construction industry?

1.2 Aim and objective

Apparently, there are obvious benefits with implementation of BIM and Concurrent Engineering in the Architecture, Engineering and Construction industry, AEC-industry (Anumba, Cutting-Decelle & Kamara, 2007). As mentioned in the background other industries have come further in implementation of multidimensional information systems and Concurrent Engineering even though they might use other terms for these concepts. So, looking to other industries and finding out their solutions is an excellent way of learning and introducing them into the AEC industry.

The oil and gas industry is a sector in which well-established information systems and well-cultivated Concurrent Engineering practices are used. The objective of this thesis is thereby to investigate the oil- and gas industry in terms of information system, work processes, communication and cooperation in order to take advantage from their experience in adapting these concepts within the AEC industry. The lessons learned from this study will guideline the AEC-organizations through introduction, implementation and development of CE within their own organization. So, the aim of this study is to find an appropriate approach for CE adaptation through investigating the oil- and gas industry. The main research questions are thereby:

- What are the benefits of BIM and CE in the AEC industry, based on lessons learned from the oil and gas industry?
- How can Concurrent Engineering be successfully introduced and implemented into the AEC-organizations?

1.3 Scope and delimitations

This study is based on investigating the working process of an oil- and gas department and a civil construction- and infrastructure department of one single company. The study covers the company’s concerns in Norway and Sweden and thereby represents the working culture in these countries with variation for organizational culture. Furthermore, the study is focused exclusively on the design phase of the projects.

1.4 Method

This study is carried out by interviews with people involved in the design phase of the projects as well as people highly involved with information systems and management control systems. The literature in the study is also based on contemporary researches on information system and Concurrent Engineering methodology.

1.5 Structure of the thesis

Chapter 2 introduces CE and BIM and gives an overview of theoretical benefits of these methodologies within AEC-industry and discusses some issues regarding implementation of these methodologies within construction organizations.

In chapter 3 the research approach that has been employed in this dissertation will be presented and argued for as well as the approach for collection and analyses of data.

Chapter 4 is a presentation of the findings of the study based on the interviews and observations.

Furthermore, in the chapter 5 the result of the study is compared to previous studies and connects the findings to the literature.

Chapter 6 represents the conclusions of the study and signalizes the limitation of the study as well as suggestions for future research.

2 Theoretical framework

According to a study from the US, the general productivity has increased more than 200% since 1960 and for the same period the productivity has decreased to 80% for the construction industry (Ahmed et al., 2014). Other industries, like the car manufacturing industry, have been able to increase their efficiency by introducing Product Lifecycle Management (PLM). PLM is a systematic, controlled concept for managing and developing products and product related information throughout the product life cycle, from initial idea to the scrap yard (Immonen & Saaksvuori, 2008). The ideas of PLM have laid the foundation for BIM within the construction industry. Rethinking product development helped the manufacturing industry to offer products with higher quality to a lower cost, so why shouldn't construction industry obtain benefits of going over to a project-life -cycle thinking.

Another concept for increasing the efficiency within the AEC-industry is Concurrent Engineering. This concept has its roots from aerospace industry and NASA (Smith, 1998). This concept has successfully been used in other industries with efficiency as a result. In order to investigate the applicability of BIM and Concurrent Engineering within the AEC-industry this study will give an introduction of BIM and CE terminology, concept and implementation in this sector.

2.1 Concurrent Engineering

Concurrent Engineering (CE), also called concurrent design, simultaneous engineering or parallel engineering, is a concept that involves several other concepts and methodologies. Concurrent Engineering has its root from the manufacturing industry. One of the earliest and most cited definitions of CE in the literature can be tracked to Bertrand et al (1988, P. 2):

> "Concurrent Engineering is defined as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule and user requirements".

The key feature of the CE approach is the integrated and concurrent design of the product and processes (Pennell & Winner, 1989). The concurrency refers to the way the product activities are scheduled, and the integration refers to the relation within the multidisciplinary team and how the product information is used for aligning the different work processes. According to Anumba, Cutting-Decelle and Kamara (2007, P. 2) the main features of CE can be summarized to:

- Concurrent and parallel scheduling of all activities and tasks as much as possible.

- Integration of product, process and commercial information over the lifecycle of a project; and integration of lifecycle issues during project definition (design).

- Integration of the supply chain involved in delivering the project through effective collaboration, communication and coordination.

- Integration of all technologies and tools utilized in the project development process (e.g. through interoperability).

The first feature of CE methodology refers to how activities and processes are scheduled during the design phase. By organizing the activities and processes in a way that they can overlap or be performed simultaneously the manufacturer could deliver a product in less time and cost (Loch and Terwiesch, 1999). This best concurrency and simultaneity is achieved by parallel work groups, parallel product decomposition, concurrent resource scheduling, parallel processing, minimize interfaces, transparent communication, and quick processing (Prasad, 1999).

Integration of all life-cycle information during the project definition is another key feature of CE. In the traditional sequential approach the information flow is unidirectional from left to right, as illustrated in the Figure 1, but in the CE approach the information flow is bi-directional which allows the decisions to be considered based on both upstream and downstream inputs (Pennell & Winner, 1989).

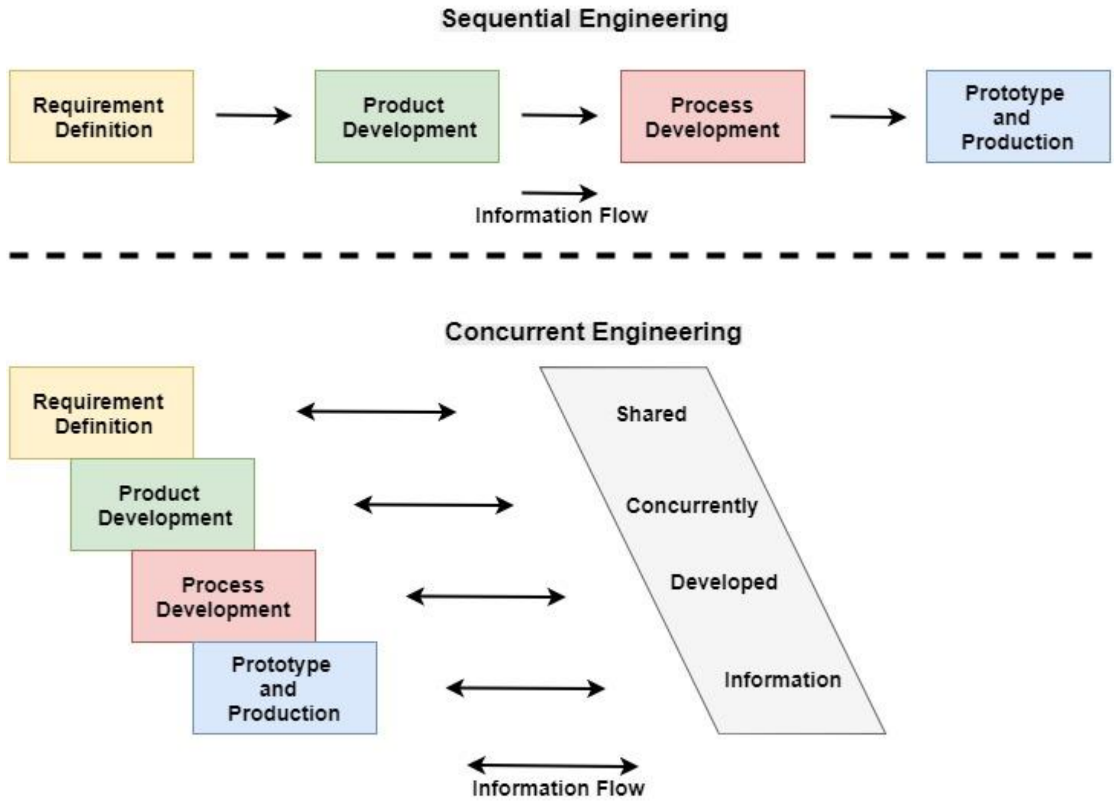

Figure 1 *A comparison of Sequential and Concurrent Engineering (Pennell & Winner, 1989, P. 648).*

This integration of all life-cycle information enhances consideration of downstream aspects of a construction project such as constructability, material selection, safety, cost, and overall development time throughout entire development of a construction project (Gunasekaran & Love, 1997). By integration of upstream information e.g. client requirements the designer will have the opportunity to consider conflicting design requirements and constrains with other associated issues such as manufacturing, maintainability, etc. (Anumba and Evbuomwan, 1998). Concurrent and bi-directional information flow makes it also easier to react to late changes in the design or client requirements (Walker, 2006).

This holistic approach and integration of both downstream and upstream information during the design phase prevents the sub-optimization of each phase and process and enhance the optimization of overall project costs and benefits (Paulson, 1976).

Another feature of CE is integration of the functional disciplines, i.e. clients, architects, structural engineers, quantity surveyors, mechanical/structural services engineers, contractors and materials suppliers, at the early stages of the construction project. In the traditional design and construction process each discipline works independently from another and then pass the information to the next discipline which leads to “over the wall syndrome” (Anumba and Evbuomwan, 1998), see Figure 2.

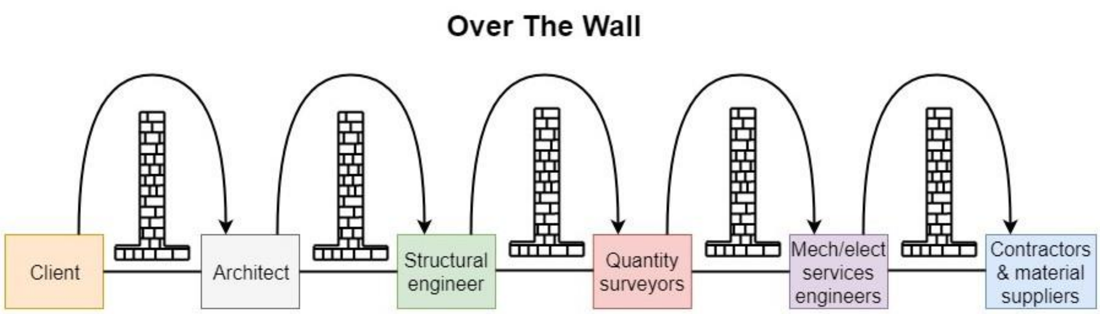

Figure 2 The traditional design and construction process (Evbuomwan and Anumba, 1998, P. 588).

This fragmentation restricts the life-cycle analysis of the project and obstructs the communication of design rationale and intent and lead to unsynchronized decisions that inevitably effect other disciplines (Evbuomwan and Anumba, 1998).

Concurrent Engineering seeks to avoid this fragmentation by involving the supply chain during the design phase (Figure 3). This integration leads to a more effective life-cycle management and decreases the need for the redesign due to unsynchronized decisions (Prasad, 1995).

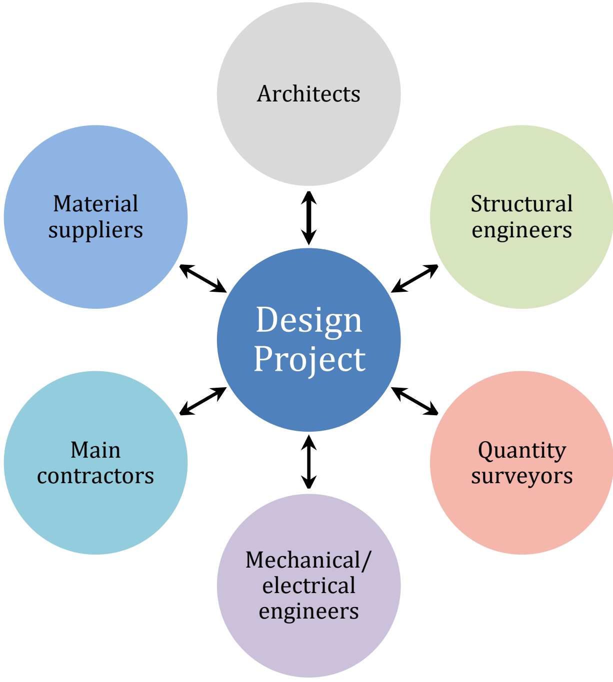

Figure 3 A typical project team in concurrent design and construction (Anumba and Evbuomwan, 1998, P. 589).

Integration of all technologies and tools that are utilized in the project development process is another central feature of CE. Working in a project involving many stakeholders requires a continues exchange of information (Fischer, Hartmann & Haymaker, 2009). Thus, communication between these different stakeholders requires integration and fusion of information in different data formats for support and improvement of the construction processes (Boukamp and Elghamrawy, 2010). Developments within Information Communication Technology, ICT, have produced a variety of new computer-based tools to enhance the communication within the construction industry (Froese, 2009).

One of the most promising developments in ICT within the construction industry is Building Information Modeling, BIM. BIM is a modelling technology and the related set of processes to produce, communicate and analyze building models which includes all aspects of the design, construction and operation of a building (Eastman et al., 2011). Due the importance of BIM as a facilitating tool for CE strategies this topic will be further described in the Section 2.3.

2.1.1 Concurrent Engineering Framework

CE was introduced as a strategy for increasing product quality, reducing product cost and minimization of product development time (Bertrand et al., 1988). These objectives are achieved by integrated and concurrent processes, use of multidisciplinary teams, early consideration of life-cycle issues, and up-front requirement analysis (Trygg, 1993). Implementation of these strategies are facilitated by use of different tools and techniques like Quality Function Deployment, agent- and knowledge-based techniques, or other ICTs (Anumba, Evbuomwan & Kamara, 2000).

By embracing CE the construction organizations could gain significant competitive advantages and a greater customer satisfaction (Gunasekaran & Love, 1997). An overall framework for CE methodology can be seen in Figure 4.

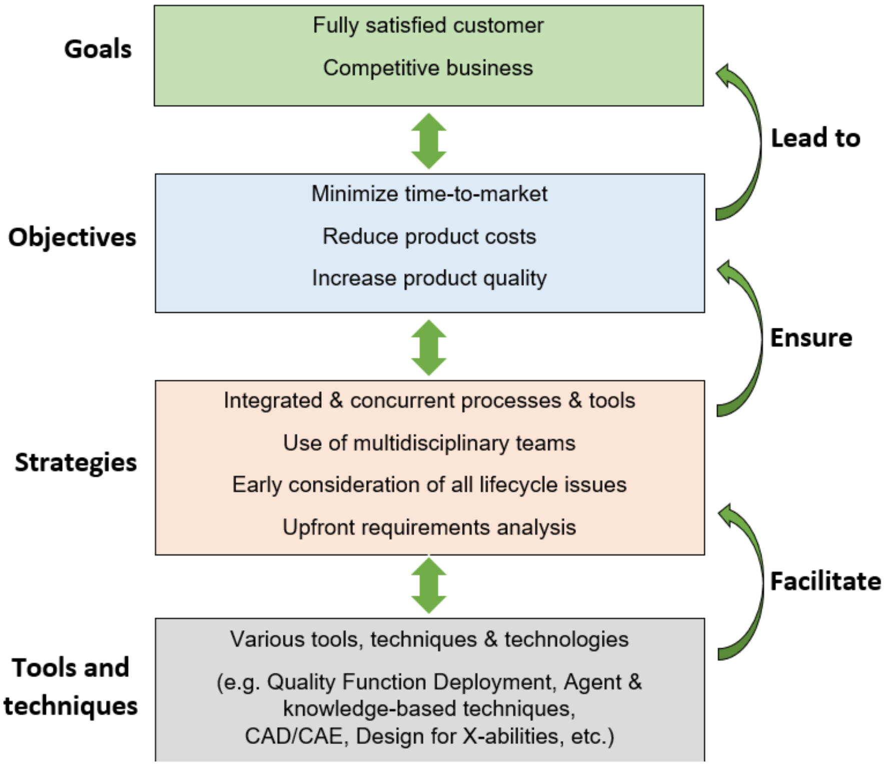

Figure 4 Concurrent Engineering framework (Backhouse and Brooke, 1998, P. 3038)

Performing the tasks simultaneously and scheduling the activates so that they can be overlapped could lead to development rework specially if the development uncertainty is not resolved at the early stages and the setbacks would exceed the benefits of activity overlapping (Loch and Terwiesch, 1999).

Working in multidisciplinary teams and a closer cooperation with other disciples increases the complexity of the design due to numerous considerations that need to be taken to account. This leads to a greater amount of constrains and more diverse design objectives and managing these issues could obstruct the implementation of CE's operation method (O'Grady and Wu, 1999).

Another disadvantage of working in CE is the risk of increased information review. Even though frequent reviews enable parallel development and early detection of design flaws it could also lead to redundant information and review time that otherwise would not be necessary (Ha and Porteus, 1995).

Furthermore, evaluation of CE performance is a complicated issue which makes it hard for the decision-makers to consider the implementation of CE within the organization (Jie, Shouke & Zhuobin, 2010).

2.1.2 Implementation of Concurrent Engineering

Implementation of CE requires a series of changes on how an organization works and how the projects are performed within the organization. In order to enable integrated processes and multidisciplinary teams the organization needs to provide the project team with the necessary environment and tools. According to Anumba and Khalfan (2000) requirements for CE implementation can be divided into two main aspects: managerial and human aspect and technological aspect. Furthermore, each of these two aspects embodies four elements which are presented below (Anumba and Khalfan, 2000, P. 578):

The managerial and human aspect:

- The use of cross-functional, multi-disciplinary teams to integrate the design of products and their related processes.
- The adaptation of a process-based organizational philosophy
- Committed leadership and support for this philosophy
- Empowered teams to execute the philosophy

Technological aspect:

- The use of computer aided design, manufacturing and simulation methods (i.e. CAD/CAM/CAE/CAPP) to support design integration through shared product and process models and databases.
- The use of various methods to optimize a product's design and its manufacturing and support processes (e.g. DFM, DFA, QFD).
- The use of information sharing, communication and co-ordination systems.
- The development and/or adaptation of common protocol, standards and terms within supply chain.

2.2 Concurrent Engineering in construction

There are several different approaches in construction industry that share similar attributes with the CE methodology. Extreme Collaboration, XC, is one of these approaches originally developed by NASA's Jet Propulsion Laboratory (Mark, 2002). XC is a project development method intended to perform complex project rapidly by collocation of design team participants, use of multiple high performance descriptive and predictive engineering models and excellent shared visualization (Ekstrom et al., 2004). Another approach similar to CE in construction is Virtual Design and Construction, VDC, and is defined as the use of multi-disciplinary performance models of design-construction projects, including the Product, Design-construction-operation Organization, Work Process, and Total Economic Impact to all stakeholders (Fischer, Kunz & Levitt, 2003).

In order for CE to be successfully implemented it has to suit the industry, the organization and the project. The manufacturing industry has been gaining significantly from implementation of Concurrent Engineering (Kusiak, 1993). The manufacturing industry can be perceived fundamentally different from the construction industry due its fixed location and mass production of products but Anumba, Cutting-Decelle and Kamara (2007) argue that the similarities between these two industries are not in the repeated products but in the repeated processes in the design and production of products.

Design and production of new products involve processes that are not only similar between different projects but also similar between different industries (Crowley, 1998). Design of new products or projects in both industries involve multidisciplinary teams which intent to introduce new engineered products by processing and assembling materials for providing a service to an end user. Moreover, both industries experience similar challenges that can directly be related to the goals and objectives of CE. Some of these issues in construction industry and their related CE strategies can be seen in the **Fel! Hittar inte referenskälla.**.

Tabell 1 Improving construction efficiency by concurrent construction strategies (Gunasekaran and Love, 1997. P. 159)

Criteria	Construction issues	CE strategies
Quality	Clients' and end user requirement	Systematic consideration of clients and end user requirements
Information flow	Interaction between participants	Team-building, proactive management, collaboration decision making
Efficiency	In-depth constructability analysis	Focus on the design and development phase
Project completion time and cost	Subcontractors, major subcontractors, rework and errors, inflexible procurement system	Quality design and documentation, involvement of subcontractors and major contractors during the early stage of the design phase, CIM, robots
Major cultural, behavioral, organizational issues	Client and end user participants for co-operative supported work	Leadership, motivation, incentives, training, multimedia
Design optimization	Non-value adding activities, delay in the project completion	Design for constructability, design for quality
Elimination of non-value adding activities	Physical movement of resources, information exchange, and hand-over between subcontractors	JIT, life cycle design, design for construction, activity-based analysis

2.2.1 Introduction of CE in construction industry

Considering the exceptional benefits that can be gained by using CE it has a long way before being used in construction industry. There are many barriers that hinder a breakthrough of CE. The main reasons hindering the CE implementation are the conservative nature of the construction and resistance to adaptation of new technology and working method (Anumba & Evbuomwan, 1998) and lack of awareness and understanding of the CE benefits and principles (Anumba, Cutting-Decelle & Kamara, 2007). Furthermore the client in the construction industry, which is an important part of the project and pays for the project, is usually not part of the industry and has little or no knowledge about the industry (Gunasekaran, Li & Love, 1998). Therefore more education and training for CE is needed and more information about its benefits especially for the client who will be the ultimate winners of CE introduction.

Another reason that hinders CE introduction to the construction industry is the traditional approach of tendering process where the projects are often rewarded to the lowest bidders (Gunasekaran, Li & Love, 1998). So a change in regulation, where the best value is more preferred, is another approach for facilitation of CE introduction.

2.2.2 Implementation of CE in construction organizations

Implementation of CE within an organization requires that the organization sets up clear strategies to support both the technological aspects and managerial- and human aspects of CE (see chapter 2.1.1). It is however easier said than done, because it requires changes in how tasks are performed, and changes in the structure of an organization. Implementation of CE needs therefore preparation, reorganization and interventions in the way projects are performed.

The introduction of a new concept and processing it until it's fully implemented within an organization, involves going through several phases and implementation of CE is not an exception. In order to methodically implement CE within an organization it is beneficial to be aware of these phases and their related activities. A theoretical framework for different phases of CE implementation is introduced below.

2.2.2.1 Four phases of CE implementation

Implementation of CE can be divided into four dynamic phases (Deasly and Lettice, cited in Khalfan, 2001). These phases are more or less applicable to any other changes within an organization and are delineated in the Figure 5.

The first phase of introducing CE is preparing for changes, which means getting familiar with the CE methodology and the changes that it means. This phase is an important commitment building phase that largely impacts the success of future phases. The next phase in instituting the concept involves creating multidisciplinary teams and a suitable environment for working in CE. These phases are followed by a phase where the boundary between team members and the rest of the organization is managed and eliminated. Sustaining CE makes up the fourth phase of the CE implementation and involves all the activities that help the organization maintain and develop its concurrent engineering practices (Khalfan, 2001).

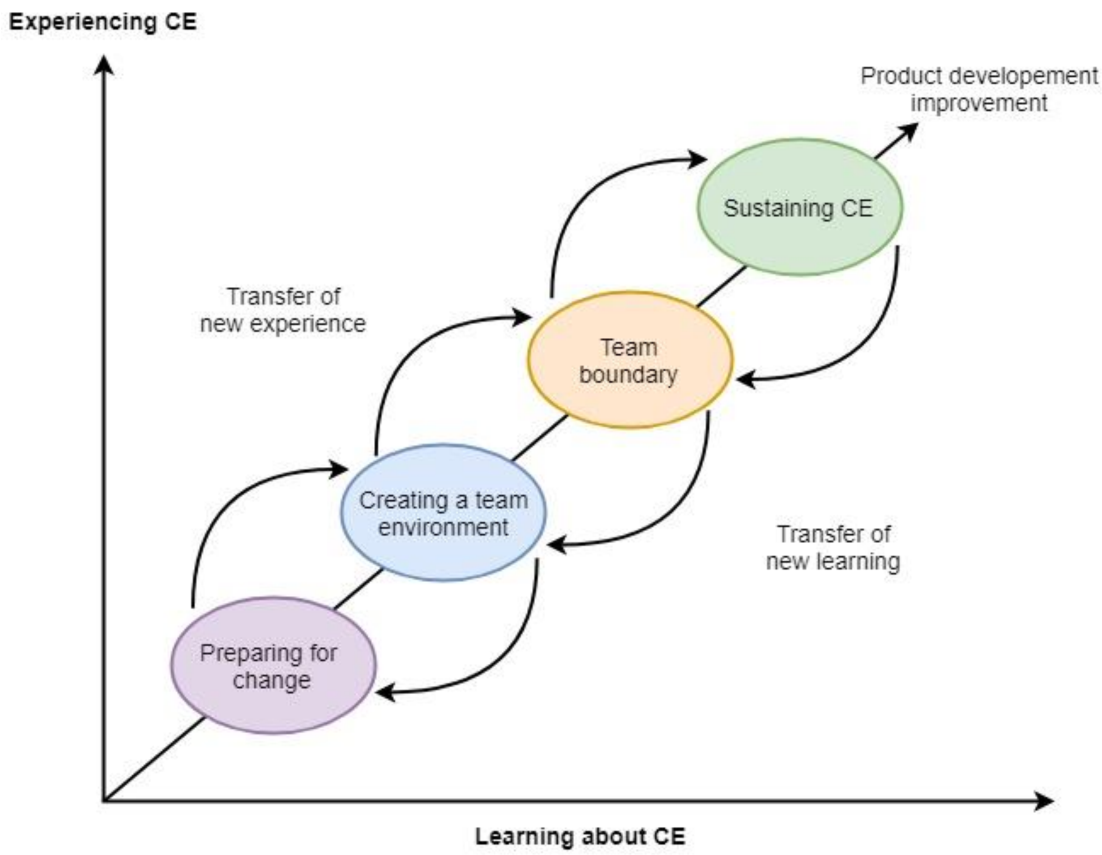

Figure 5 Four dynamic phases of CE implementation process (Deasly and Lettice, cited in Khalfan 2001, P. 29)

2.2.2.2 Barriers of CE implementation and how to deal with them

Introducing new concepts involves consequently implications and barriers that might harden a successful implementation of it. It is therefore important to discover these barriers beforehand and prevent them in order to make the transition as flawless as possible. Some of the main obstacles in implementation of CE in construction projects are regarded to the relationship between team members. Project teams in the traditional projects are fragmented and each discipline tries to optimize their own work without consideration of the good for the project as a whole (Paulson, 1976). This relationship between disciplines decreases the trust between team members and facilitates for opportunism.

In order to overcome these barriers Khalfan (2001) points out ten Critical Success Factors (CSFs) that can help to successfully implement CE within an organization. These success factors have been detected by studying implementation of CE in other industries and can directly be associated to the four phases of CE implementation. These ten CSFs are stated below under related implementation phase presented by Khalfan (2001, PP. 30-33).

Phase 1: Preparing for change

CSF 1) Development and Dissemination of Management Intention

A clear understanding of the CE methodology and implementation issues is required from the senior managers.

CSF2) Change Agents
The senior managers should appoint a change agent as the like of BIM manager or the BIM committee for preparation and development of CE implementation as well as support and training of the CE team.

CSF3) Pilot Projects
Before an extensive turnaround of the organizational a few pilot projects are vital for progressive implementation of any changes within any organization.

Phase 2: Creating a team environment
CSF4) Integrated Product Development Teams
An integrated product development team should be appointed with consideration of the members' availability and technical abilities. It is important that all functional disciplines are involved specially in the early design stage during project development process.

CSF5) Collocation
The product development team needs a common location for an effective collaborating and continuously information sharing due a high interdependency between the different disciplines.

CSF6) Team confidence
The CE team requires full confidence and support from the senior manager who needs to clarify and communicate the role and responsibility of the project team.

Phase 3: Team Boundary Management
CSF7) Develop Team Environment Interfaces
For an optimal and well-functioning CE team and integration of the CE team within the organization the senior manager must understand and communicate the interface between the CE team and the rest of the organization and communicate these to all employees.

Phase 4: Sustaining Concurrent Engineering
CSF8) Team Based Reward Systems
As CE encourages and focuses on the team performance rather than personal or discipline-based performance new reward system needs to be introduced in order to promote the new multidisciplinary working practices.

CSF9) Managing integrated Product Development Projects
In order to enhance integrated product development project it has to be streamlined with the organizational structure and the business processes of the organization.

CSF10) Developing Integral Learning Processes
After the initial projects the organization needs to transfer the experience further within the organization through various learning processes such as project reviews, seminars, workshops etc.

2.3 BIM

As mentioned BIM is a state-of-the-art and promising development within ICT to turn the inefficiency around in the construction sector (Broquetas, Bryde & Volm, 2013). BIM is defined as a modelling technology and the related set of processes to produce, communicate and analyze building models which include all aspects of the design, construction and operation of a building (Eastman et al, 2011). BIM is an acronym which has come to stand for several distinct yet interconnecting concepts such as Building Information Model (Adriaanse et al., 2012), Building Information Modeling (Broquetas, Bryde & Volm, 2013) or Building Information Management (McArthur, 2015). In many BIM researches these terms are used interchangeably but what is essential with this differentiation is to emphasize that BIM should not be seen exclusively as a new technology but a new way of collaborating and performing construction projects consisting of interoperable technologies, integrated processes and collaborating people (Kimmance, 2002).

The BIM methodology circles around the Building Information Model. The model in BIM differs from conventional 3D-models by being object-oriented (Ibrahim and Krawczyk, 2003). This means that instead of lines and texts, the design in these models represent smart objects that contain further information about e.g. the geometry, relation and attributes of the object which in turn opens the door for numerous applications in building's construction, management, operations and maintenance (Abbott et al., 2005). According to Eastman et al (2011, P. 16) the model in BIM is characterized by:

- Building components that are represented with intelligent digital representations (objects) that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion.

- Components that include data that describe how they behave, as needed for analysis and work processes, for example: takeoff, specification and energy analysis.

- Consistent and non-redundant data such that changes to component data are represented in all views of the component and the assemblies of which it is a part.

- Coordinated data such that all views of a model are represented in a coordinated way.

This means that a door in a BIM model is defined as a door and contains information about its properties and relations to other components of the building. When this door is placed into a wall it will automatically fit into the wall and a light switch will be placed at the proper side of the door. A change of the door in one view is automatically reflected in other views. The door can also contain information about its price, thermal resistance and sound resonance; and this information can be used or exported to other programs for example for cost estimating, energy analysis or acoustic analysis (Ibrahim and Krawczyk, 2003).

There are many software developers that offer object-oriented BIM-tools such as Autodesk Revit® Architecture and Structure, Bentley Architecture and its associated set of products, Graphisoft ArchiCAD®, Gehry Technology's Digital Project™, Nematschek Vectorworks® and Tekla Structure (Eastman et al, 2011). These programs allow creation and edition of a design and export of data in different formats for integration in other programs. The integration of the BIM model in other programs can happen either by using products of the same software provider or using software from various providers that can exchange data using industry supported standards like IFC (Becerik-Gerber and Kensek, 2010). Industry Foundation Classes, IFC, is a major standard for BIM (Björk and Howard, 2008) which provides a rich schema for interoperability through object-based transactions (Eastman, Teizer and Venugopal, 2015).

2.3.1 BIM applications and benefits

The integration of different software into the BIM model creates various applications that can help the actors within the AEC industry to increase their efficiency, productivity and profitability (Azhar et al, 2008). According to Eastman et al (2011) BIM applications can be divided into four different phases of a construction project: Preconstruction phase, design phase, construction phase; and post construction phase. Since the thesis only focuses on the design phase, the use of BIM during design is discussed in more detail.

During the design phase which is the focus of this study the BIM can be used for early and more accurate visualization of the design, evaluation of alternative design; and enhanced modification of the design at the time when changes are easy to implement (Arayici and Mihindu, 2008).

Cost estimation is another area that BIM can be useful for during the design phase. An accurate bill of quantities can be generated out of a BIM model at any stage of the design which can get even more accurate as the design matures (Eastman et al, 2011). Moreover, the amount of work and price can be linked to the elements of the design (Plebankiewicz, Skibniewski & Zima, 2015).

Integration of a BIM model with energy analysis tools allows a more efficient and dynamic simulation of energy use during the early design phases and moreover supports performance tracking during operation and maintenance (Hänninen, Karola & Laine, 2007). Furthermore, implementation of BIM creates a great opportunity for sustainability measures to be incorporated throughout the design process by giving access to an extensive set of data in relation to the building's form, materials, context, and MEP systems (Ahmad et al., 2011).

Concerning Concurrent Engineering, the BIM technology, as an effective ICT tool, facilitates simultaneous work by multiple design disciplines (Eastman et al, 2011). Working with one or more coordinated 3D model improves the communication and coordination of the design processes due to automatic coordination and improved workflow (Broquetas, Bryde & Volm, 2013). This enhanced communication and interoperability facilitates an integrated collaborative multidisciplinary mode of operation (Fischer, Haymaker & Kam, 2005).

A fully integrated BIM methodology moves the construction project towards a phase-less process where all project life-cycle phases are overlapped through a synchronous exchange of data (Succar, 2009) see Figure 6.

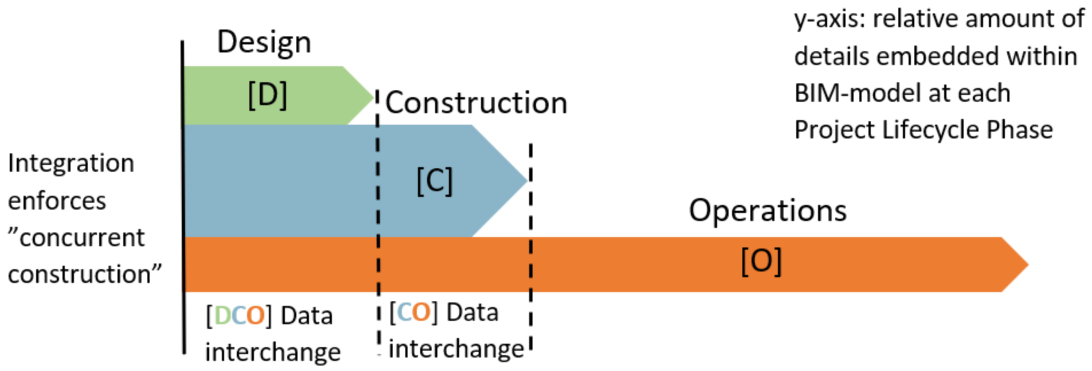

Figure 6 Project Lifecycle Phases at BIM (Succar, 2008, P. 367).

The benefits that derive from implementing BIM as tool for communication and integration of technology, processes and people makes it a vital mean for facilitating CE implementation (Succar, 2008).

3 Research Methodology

In this chapter, the research approach that has been employed in this dissertation will be presented and argued for as well as the approach for collection and analyses of data.

3.1 Research approach

Qualitative- and quantitative research methodologies are the two main research methodologies that are used within social researches. Qualitative research methodology emphasizes on words and tries to describe a process or a phenomenon. This research methodology is characterized by being inductive, which means that the research is used for generation of theory. Qualitative research is also constructionist, meaning that the result of the research is an outcome of the special context. Furthermore, as a social research, qualitative research is interpretive, which means that it is based on individual interpretation in that special context (Bryman, 2012).

Quantitative research methodology is on the other hand characterized by the collection of data and measurement and is used for verifying a theory. In contrast to qualitative research, quantitative research is deductive which means that the theory is used as a basis for the research. Moreover, quantitative research methodology is subjective and takes a scientific approach to validate the theory or to make more generalized theories (Bryman, 2012).

Since the aim of this study is to investigate the oil and gas industry- and try to understand their values, beliefs and working processes and learn from their experiences in order to propose a theoretical platform for the AEC-industry, the qualitative research methodology has been used as a more appropriate research approach for this study.

3.2 Case study

As described in the background the working process of an oil and gas organization is used as a case study for carrying out this study. According to Yin (2003) a case study is an empirical enquiry for the investigation of a real life phenomenon within its real life context. In a case study the boundary between the phenomenon and the context is not clear and it can be explored for examination of the phenomenon under the contextual conditions of the study. Therefore, in this study, the context of oil and gas industry is explored in order to examine the application of CE within the context of the AEC-industry. Furthermore Yin (2003) argues that using a case study is preferred when the focus of the study is to answer "how" and "why" questions where the investigator has little control over the events.

The organization studied in this research is a Norwegian consulting and contracting company and operates within the market areas of oil and gas industry, civil construction and infrastructure. The organization operates mostly in Norway and Sweden and has more than 2300 employees whereas 300 in Sweden.

3.3 Data collection

3.3.1 Theory

Cody and Mitchell (1993) propose that, by nature, inquiry, discovery and theoretical interpretation coexist and must be recognized as such. So even if a qualitative research is an inductive and interpretive inquiry and a result of a special context there is a need for a theory as a linkage between the findings and result of a qualitative research. Therefore, a literature review has been performed for the generation of a theoretical framework concerning the subjects and presented in the previous chapter. The aim of a literature review is to bring the reader up to date with current literature (Höst, Regnell & Runeson, 2006). The literature used in this study is based on contemporary books and researches concerning BIM and CE as well as other supporting issues.

3.3.2 Interview

For carrying out this research, several persons within the Oil and Gas department as well as the Construction department of the case study have been interviewed. The interview is one of the most effective ways of gathering data in qualitative research. Kvale (1996) describes qualitative research interview as “an interview whose purpose is to obtain descriptions of the life world of the interviewee with respect to interpreting the meaning of the described phenomena”. So the focus of a qualitative interview is to know the perspective of the interviewee on the specific subject and understand why and how they have that specific perspective.

Since qualitative research is a descriptive study and tries to answer “how” and “why” questions using a semi-structured interview is the most appropriate structure for the interviews in this study. The advantage of a semi-structured interview is that there will be room for open discussions and conversations and, at the same time, have a focus on the main subject. During the interview questions concerning the information system (BIM), the work process and work meetings, information sharing outside of the meetings and lessons learned.

In total seven different interviews have been carried out during this study. The interviewees have been chosen regarding to their position, responsibilities and experience on the subjects. In order to cover a holistic perspective of the subject and increase the validity of the findings it is tried to select interviewees with different functions and roles. Within the oil and gas department three different employees have been interviewed:

A: Project manager and section leader
B: Instrumental engineer
C: Manager of collaboration and integrated operations

Within the construction department four employees have been interviewed:

D: Section manager within building and industry and representative division leader within construction
E: Structural Engineer and BIM coordinator

F: BIM- coordinator within the division and in charge of BIM development within the organizations institution in Sweden
G: Member of the management group and in charge of the organizations BIM group in land.

In order to increase the reliability of the sources the interviews were recorded and transcribed. The interviews were performed in English, Swedish or Norwegian. In the case of the latter two they were first translated to English before further interpretations.

3.3.3 Observation

Field observation is another source of information in doing qualitative research and an effective way for understanding the process and structure of a social context. It can be used for studying the impact of an event as well as obtaining a inside view of reality. Using field observation in addition to interviews gives extra source of evidence and strengthens the accuracy and validity of the study. Therefore, in this study a field observation has been applied by being part of the organization during several months. Observations during this time have been a great contributor for a holistic understanding of the organization environment, working process and attitudes regarding to the subjects.

3.4 Data analysis

A problem with qualitative research is that it can generate a large amount of data. Bringing order to the data and highlighting useful information, as a basis for valid conclusions, requires interpretation and appropriate data analysis method. Therefore, in this study a thematic analysis has been used as an appropriate data analysis method. Thematic analysis is the most common form of analysis in qualitative researches and focuses on identifying and describing both implicit and explicit ideas within the data, that is, themes (Guest, MacQueen & Namey, 2012).

In order to facilitate data analysis and ensure the validation of the study the interview questions have also been categorized under several themes. The first theme of the interview questions dealt with the current information system within the respective department, followed by the current working processes and meetings of the department. Furthermore, the process of information sharing outside the meetings has been explored. Finally lessons from the oil and gas department has been discussed and reflected on. Furthermore, these questions have been adapted to suit the function and role of the interviewee. The interview frameworks as a whole can be found in the appendix of the report.

3.5 Research ethics

Developing studies and doing interviews to gather business research involve different ethical issues that are needed to be considered in order to maintain objectivity and increase the credibility of the research. Ethical principles in business research focus on the way information is collected and presented. According to Bell and Bryman (2015) four main areas of ethical principles within business research are: harm to participants, lack of informed consent, invasion of privacy and deception. In order to prevent transgressions of these principles the participants were informed about the purpose of the study and the structure of the interview before the interviews. Furthermore, the interviewees where asked to give their consent to be audio-recorded during the interview and confirmed the transcription of the interview. Moreover, the data presented in the findings are mentioned anonymously by field of occupation.

4 Result

This chapter presents the result from the interviews. The result is presented as a compilation of the answers from the interviewees under specific themes.

4.1 Work processes and meetings

4.1.1 Oil and gas industry

Regarding the work processes and meetings it is obvious that the organization has a clear strategy and systematically developed practices. All projects within a certain scale should be done through an approach they call Concurrent Methodology, which is an own developed variation of Concurrent Design. The methodology is based on the idea that the different disciplines involved in a project get together in work sessions in the same room. It is important to know that it is a work session and not a meeting, as the interviewee A emphasis: "*There has to be pure working during these meetings… The meetings are solution-oriented, where the problems are solved there and then*". Progress is also a central concept in this methodology and is attained by a good interface between the disciplines. This interface allows that all disciplines get what they need from others in order to move on with their own work.

Using this methodology, the organization has obtained noticeable benefits. One of the main persons behind the development of this methodology is interviewee C who sums up these benefits to: "*The project members have better understanding of the scope of the project. The new employees learn faster and get more multidiscipline by seeing what other disciplines do. It is much more fun and it is important to have fun while working in team and it reflects on the result. We have also managed make the design phase more smooth by cutting the unnecessary waiting time between the decision and action*." She mentions also that it is hard to measure how much faster the design is performed because it can depend on several interconnected factors.

The organization has developed a series of practices in order to adapt the methodology into their organization and projects. Because project members don't work exclusively with one project they have a work session only about once a week, which lasts for 3-4 hours. A work session can have a freeze layout, which is the goal of the working session. It is also this layout that decides which disciplines should be presented in the work session. If a specific discipline is needed to fulfill the goal of the day they should be presented at the session. If a discipline has a small part of the project and is not highly involved the session they can bring their own laptops and even work with other projects but they have to be there in case anyone else needs them. One of the participants thought that it can be too much unnecessary information during the sessions but in general it's good to have an overview of the project.

The project team uses also a dedicated project room called the Concurrent Room. In this room there is one PC for every participants and big screens on the wall. There is also a control panel where the project manager can choose which pc-screen to be shared on the wall.

The project managers in these sessions have to undertake the role of a facilitator. The organization organizes therefore special courses on leading a Concurrent Methodology work session. The role of a facilitator is described as a teacher who needs to pull on the lines to get input from everybody and thereby get the best of everyone. The facilitator leads the session and starts with telling the goal of the day and what do they want to accomplish at the end of the day and tells how it is considered to be carried out. And then the project leader asks whether there is something that hinders them from reaching the goals of the day. Afterwards the facilitator continues with a short statue round and asks how long everybody has come and whether they have any "project killers" -if they have any obstacles- or if they have anything they need to bring up.

The Concurrent Methodology is always used in the pre-studies of the projects but in performance of the projects it is not always used. They don't use it when the project is too small or too big. As estimation projects, less than 3000 project hours are not done with the Concurrent Methodology.

The reason the organization has started with this methodology is requirement from a client but since it worked well they have kept up with that. In order to drive the methodology forward they have realized that there should be someone who drives the methodology forward and therefore they have chosen two persons who work entirely with integration of the methodology into their system. Not everything worked well already from the beginning but it has been developed and is developing in order to get the best out of the methodology. For instance, not everybody is comfortable working in such sessions and need to be coached. The organization has even started to, beyond for the project managers, have courses for other participants as well.

All interviewees agreed about that this methodology could be beneficial for the AEC-industry as well. The interviewee A goes as far as: "*as soon as you have a multidisciplinary task you should do it in concurrent design*". The project participant agrees on that and indicates that it's a matter of attitude and the size of the project does not matter. They suggest that the AEC-industry should at least try it and see the benefits that it gives to the project as whole. Furthermore, they suggest that the AEC-industry should develop their own practices in order to get the best out of the methodology and adjust it according their own conditions.

4.1.2 Construction industry

The design phase of the construction department is carried out by different type of meetings. The main type of the meeting is the traditional design meeting. These meetings take place almost every other week where the different technical disciplines bring their own drawings and discuss issues that concern other disciplines. There is also another type of meeting called engineering meeting, which is hold only between two disciplines. Even these meetings are held every other week so that they can more closely cooperate and exchange information. There is also a third type of meeting called BIM-meeting or clash control meeting. In these meetings, the design of the different disciplines is gathered into a 3D-model and constructability issues are discussed and solved. None of these meetings can be compared to the Concurrent Methodology, as the problems are not solved during the meeting but they are brought up to be solved by the next meeting. The traditional meetings have some limitations that make them ineffective. A well-recognized limitation is that issues, brought up at the meeting, are often not solved by the next meeting which delays the work of other disciplines.

All the interviewees agree on that Concurrent Engineering could work well for them. There are however several issues that hinder them from using it. The biggest issue mentioned is the size of the project. Most of the projects of the construction department are perceived to be too small to be worth working in Concurrent Methodology. There are different views on how big the projects should be and this varies between 60 to 400 million SEK construction projects or over 20.000 design hours. Implementation of CE is also presumed to require tying up the staff with one single project, which would be unacceptable in smaller projects.

The next big issue regarding the implementation of CE is the traditional way of working. The interviewees admit that people tend to perform the work as they always have done and this will not change until it's a demand from the client. Another issue that opposes the methodology is that implementation of CE requires extra resources in form of special designed rooms with computers for everyone.

The leading board and the senior management are mentioned to be an essential driving force for implementation of CE as interviewee E puts it: "*I think the department managers could play a key role in implementing these methods. Because if you are going for these you might need to invest for equipment and special meeting rooms for these kinds of meetings. It is also the department managers' responsibility to change the way we are sitting at the office and rearrange the design team and the way the projects are performed*"

Furthermore, there are some issues regarding practical issues in using CE. For instance, the person who is drawing in the model is not the same person as the one who is calculating which in turn is not the same person who is deciding. Another issue mentioned is that participating in CE meetings could demand more from the participants and they are supposed to know everything during the meetings. There are also some issues that question the applicability of CE within the construction sector. For instance, sometimes there are some waiting times before some activities so it has to take its time anyway, which make working in CE unnecessary.

However, the interviewees in general are positive about trying out the methodology and there are also plans for doing that. CE has already been used in pre-study of some projects with better result and better bids for contracts. The interviewees make also some suggestions on how to approach to successive implement it. It is for instance suggested that there should be someone within the organization who drives the methodology forward in order to get everyone from the leading board to project managers and other employees onboard. Interviewee E states: "*I think also there should be one person who manage the whole process and develop the system and take it to the next step. It should be someone knowledgeable who people seek to whenever they have practical problems. Of course, this person can be someone in the group and the structural engineers use to be good so they can take this role.*"

There are also some ideas about practical issues of the CE. Interviewee E suggests also that: "*I think the people that will use the design for their own work should also participate in these meetings because they have their own meaning of how thinks should be done the way more effective than the designers know.*" Interviewee F suggests that they should do it before every submission. They have 50%, 80% and

100% submissions and working in CE before each of these submissions would be ideal for securing the delivery.

Finally, it is suggested that the organization shouldn't wait for the demand of the client in order to start implementing CE because working in CE would lead to higher quality in their project and thereby they can get better reputation and more jobs in the future.

4.2 Information system

4.2.1 Oil and gas industry

By studying the oil and gas department it can be observed that there does not exist any systematically developed information system within the organization. The established information system has been developed organically through best practice and thereby no specific term is given to the existing information system. When mentioned, the information system is referred to the different computer programs rather than an interface between people, process, data and technology. It is however evident that these different computer programs can efficiently exchange information between each other and thereby make the interface work fluently.

The different disciplines within the industry use several different computer programs for their related activities but apparently the data transition between these different programs work seamlessly as the interviewee A puts it as: "We use a plan tool called SAFRAN. The engineers put in progress information on this program with MIPS… Then we have Agresso were we put in time and transfer to SAFRAN... After that the information is transferred to a program called Promineo, which is a cost tool and recalculate the progress in form of cost… The purchase of all material is done by SUB, which… is connected to Promineo. These programs are also used for material takeoff, cost- and time planning and material buy-in." It appears also that this information exchange between the different disciplines occurs continuously so the involved parties are constantly informed about the project progress and what to be done next.

4.2.2 Construction industry

Investigating the construction department shows clearly that the involved positions are highly familiar with BIM and the possibilities that it can bring to the industry. The interviewed positions mention also that they are using BIM into some extend but they admit also that they are far from using it into its full potential and an extensive implementation of BIM is yet to come. The fields of application of BIM are often restricted into visualization and clash control but there are plans for further development of the methodology.

As mentioned the organization operates both in Sweden and Norway and there is close collaboration between the Norwegian and Swedish department and the projects are sometimes performed cross nationally between these two departments. Nevertheless, the level of BIM implementation between these two departments is clearly perceptible with the Norwegian department being in the forefront. One of the main reasons is that the Swedish department misses the construction part. The

Norwegian department has design and builds contracts and is perceived to gain more by BIM-implementation. Another reason is that Norway in general has come further in BIM-implementation and there are requirements regarding to BIM-implementation in government projects.

3D models are used in high degree both in the infrastructure section and building- and construction section. These models are particularly used for clash control, constructability check, quality assurance and visualization. Communication is also mentioned as an important field of 3D utilization as it's a powerful tool for communicating ideas. The 3D-model from the infrastructure section is also used as a source for machinery control on the construction site. The excavating machines for instance can get the coordination data directly from the model. The building- and construction section in Norway has come farthest and has just started model based scheduling and quantity take off using Vico Office.

All of the interviewees are convinced that 3D-models and BIM can be used in a higher extend under special conditions. An important condition is mentioned to be a more knowledgeable client. If the client is aware of BIM and the benefits that it can give to the project as a whole they will be willing to pay for the extra expenses caused to the design consultancy for production of accurate 3D object based models. Another condition mentioned is the maturation of the technology. The different computer programs can't yet exchange information flawlessly and technologies like IFC need to be further developed in order to be more useful.

However, the organization seems to work with further implementation of BIM, which can be seen both from the leading board and project managers. The organization has set up a special group, concerning both Norway and Sweden, which works with development of BIM both internally and in collaboration with other organizations and educational institutes. This group is also developing BIM manuals that can be used internally within the organization. The result of the organization's ambition can be seen in the work of the project managers and the plans for further implementation of BIM applications. In Norway, there are plans to use Vico Office also for cost estimation and the infrastructure department in Sweden has also plans to use the model for time and cost estimation. The interviewees indicate also that these progresses are going to take time and have to be taken slowly and step-by-step as interviewee F put it: "*In every project we put on a little bit more and finally we will be there*".

The interviewees indicate that using BIM increases the communication and understanding between the different disciplines and also breaches the gap between the designers and the contractor. The collisions on the project site and reworks are prevented which will decrease the project cost.

5 Discussion

Investigating and comparing the oil and gas industry with the AEC industry in this report shows clearly that the oil and gas industry has come much further in implementation of an effective information system and working in Concurrent Engineering. There can be drawn many parallel lines between the working process of these to industries and the AEC-industry has a lot to win in looking to the working process of the oil- and gas industry.

5.1 Concurrent Engineering

The Concurrent Methodology that the oil and gas department uses is based on the Concurrent Design, originally developed by NASA as was mentioned by Smith (1998). It is however in accordance with the same ideas as Concurrent Engineering. Just like CE, the Concurrent Methodology is based on the two concepts of concurrency and integration (Pennell & Winner, 1989). They use similar tools and techniques to facilitate integrated and concurrent processes, multidisciplinary teams, early consideration of life-cycle issues and upfront requirement analysis (Trygg, 1993). It cannot be confirmed that time-to-market-through the projects is decreased as was advocated by Bertrand et al. (1988) but it is evident that they have managed to cut the unnecessary waiting time between the decisions and actions. It is not measured whether the project cost is reduced as was acknowledged by Loch and Terwiesch (1999) since each project is unique but there is no doubt that they have managed to decrease errors in the design which confirms previous studies by Anumba and Evbuomwan (1998) and Prasad (1995) and increase the quality of the projects (Bertrand et al., 1988). As increasing product quality, reducing product cost and minimization of product development time were the main objectives of CE (Bertrand et al., 1988) it can be concluded that these objectives, with some degree of uncertainties, have been achieved.

The construction department works with traditional sequential meetings which are explained by Anumba and Evbuomwan (1998). These kinds of meetings have some limitations that make them inefficient. One of the well-known limitations mentioned is that the decisions taken during the meetings are many times not solved by the next meetings. This delays the work of other disciplines that are dependent on the specific action, which is confirmed in literature (Gunasekaran and Love, 1997). There are also some limitations with sequential meetings that are not noticed until they are compared to CE. The oil and gas department emphasize on the interface that working in concurrent methodology offers. This interface, which is missed in traditional meetings, allows for an integrated working process that brings the different disciplines together for optimizing the whole project life cycle, which Paulson (1976) argued to be one the main benefits with working in CE.

5.1.1 Barriers of CE implementation

Both the oil and gas department and the construction department are convinced that the concurrent engineering approach could be beneficial for the construction department as well but the implementation remain to accelerate due resistance to change which is in line with previous findings pointing out resistance to change is a hinder for new methodologies (Anumba and Evbuomwan, 1998). Furthermore, even if they are aware of CE benefits they lack of awareness of CE principles and their knowledge is based on false assumptions which is aligned with previous findings (Anumba, Cutting-Decelle & Kamara, 2007). For instance, they think that the project members have to work entirely with one single project in order to work with in CE and also, they think that they have to work every day sitting in the CE work session. These assumptions make them exclude its applicability right away. Investigating the oil and gas department shows clearly that these assumptions are false. Even if the ultimate way of CE would be to work that way it is not suitable for many projects.

5.1.2 Different phases of CE implementation and CSFs

As it can be seen the oil and gas department has come far with implementation of CE and they have had significant project development improvements. As described by Deasly and Lettice (1997) implementation of CE implies getting through four dynamic phases: preparing for change, creating a team environment, team boundary management; and sustaining CE. Similarly, the oil and gas department has gone through all these phases and not everything worked well from the beginning but as they gained more experienced over time and they have gained more knowledge. They are now in the phase of sustaining CE where they are maintaining and developing its concurrent engineering practices. As mentioned in literature, Khalfan (2001) pointed out ten critical success factors (CSFs) regarding a successful implementation of CE in direct relation to these different phases. These factors, that are highlighted below, mirror more or less exactly the same experiences that the oil and gas department had experienced and dealt with.

The first phase of the implementing CE was preparing for change. There were three CSFs that were essential to consider during this phase. Before implementation of any new methodology, the department manager needs to build a clear understanding of the methodology (CSF1). So, if the construction department wants to implement CE, firstly they must understand the aim of CE and all necessary conditions that implementation of CE requires. This is an issue lifted up in the result as a prerequisite for CE implementation. Thereafter they should set special change agents that could help them with a successful implementation of it (CSF2). The oil and gas department has set two persons who entirely work with implementation and development of the methodology within the organization. The study of the construction department shows also the need of someone knowledgeable that people can seek for guidance is required for implementation of new methodology. Moreover, the most important step is pilot projects and this is needed to gain experience and find the best practice of CE within the department (CSF3). It appears also that there are plans for implementing CE within some projects within the near future.

The next step in implementation of CE was creating multidisciplinary teams. The oil and gas department has developed a number of practices regarding the team building. They have for instance developed a system with fixed goals of the session, which affects participation of necessary disciplines required for reaching the goal (CSF4). The construction department needs also to develop similar practices in order to invite only the necessary disciplines into the meetings. It is especially important not to demand client participation more than necessary. The new working process demands also more both from the participants and the project manager and therefore the oil and gas department has started to have courses in how to work in this new environment.

The project managers undertake the role of a facilitator in order to get the best out of everyone and create a good team confidence (CSF6). The team is also given a dedicated CE room for a suitable environment that working in CE demands (CSF5). They have even created project light room for smaller projects, so they keep having the benefits of CE even when they are not working with too complicated projects.

The third phase of implementing CE was team boundary management. The senior managers should develop suitable interface both within the team and between the CE team and the rest of the organization and communicate it to all employees (CSF7). Studying the oil and gas department shows clearly that CE is well established within the department where everybody is aware of the role and importance of the CE team.

The last phase of implementing CE was sustaining CE. The organization should support working in CE through all its business processes and organizational structure. Studying the oil and gas department shows clearly that how CE is supported and backed up by all other activities of the department and facilitates working in integrated project developments (CSF9). So, if the construction department wants to implement CE, the leading board needs to contribute the project managers with necessary environments for the methodology. This is something that the project managers at the construction department mentioned as well because implementing CE needs investment in special rooms and equipment that cannot be realized until it is given the green light from the leading board and the department management. Furthermore, after initial pilot projects the organization should develop create internal learning process and take the methodology to the next level (CSF10). Within the oil and gas department the change agents are also responsible for development of the methodology and the construction department should use similar systems. However, no team-based award system (CSF8) used in the oil and gas department as it was suggested in literature but it could be beneficial for the construction department especially when the client is onboard and realizes the benefits of working in CE.

5.2 BIM

Regarding to the information system, it is evident that the oil- and gas department uses a far more integrated information system that seamlessly connects the different disciplines together. However, no specific name is given to the information system in use within the oil- and gas industry. Outside the industry PDMS is often compared to the BIM, which is not the case. It is rather a drawing tool that can be used by several disciplines. When mentioned information system is referred to the different computer programs rather than a combination of information technology and people's activities that support operations, management and decision-making (Kimmance, 2002). This shows that the information system in use has been developed organically by best practice. However, this does not detract the value of how efficient the information system works within the oil and gas industry.

The construction department uses a more fragmented information system where a few disciplines can exchange information, take part of, and use each other’s work. There are of course project servers where a lot of project information and documentation can be found but mostly they aren’t useable because the information is not complete or shared in a useable way. This makes it inefficient since a lot of information that can be used by other disciplines is wasted. Each discipline tries to optimize its own work with no consideration of optimizing the whole process, which is in line with previous findings (Paulson, 1976).

It is however evident that the construction department works with implementation of BIM. The organization has set a special BIM-group who works with development of BIM. As mentioned in literature about implementation of CE, which also can be applied here, change agents (Khalfan, 2001) are an essential step for implementation of a new concept and shows that the organization is aware of BIM's potential and possibilities. The organization has also done some progresses in implementation of BIM. Using a 3D model is more or less a standard for all of the projects and clash control and constructability check. There are however just a few applications where the ultimate power of object-based models are utilized, such as in model-based scheduling and quantity take-off which were brought up by Plebankiewicz, Skibniewski & Zima (2015). Nevertheless, the true power of object-based modeling is used when it is used for further implementation such as for use in energy analysis or acoustic analysis (Ibrahim and Krawczyk, 2003), cost estimation and the amount of work and work price (Plebankiewicz, Skibniewski & Zima, 2015), etc.

There are however plans for using the model for cost estimation. This shows that the organization is on the right track for further implementation of BIM. The next step is to gear up and use BIM as a central concept for all projects so that it reflects all of the working process of the organization. This cannot be possible until the leading board and department management fully endorse the concept because management support and change agent according to Khalfan (2001) are two critical success factors for implementation of a new work methodology.

There are some factors that slow down the implementation of BIM. An unknowledgeable client is mentioned to be one of these reasons that slows down implementation of BIM which confirms the study done by Gunasekaran, Li & Love (1998). Even here the leading board could play an essential role in informing the clients and clear up the benefits that they could get by implementation of BIM. When the clients are aware of the benefits they will be willing to pay the extra work of the design consultancy. Another factor mentioned is the maturity of the technology. The different software programs are not fully integrated. Open file formats like IFC (Becerik-Gerber and Kensek, 2010) are mentioned to be incomplete. Even if IFC is not flawless it has come far and can be used in a lot of applications. However, it cannot be fully developed until it's really tested and used in real projects.

The Norwegian department has come further in implementation of BIM since they have the construction part in house. This shows that the organization sees benefits of implementation of BIM but on the other hand shows also that the Swedish organization underestimates the value of BIM implementation for them just as a design consultancy. A reason why the organization strives to implement BIM is mentioned to be because everyone else is doing that, so they must also follow the development. Even if this condition forces the organization to try to implement BIM it's not the ideal attitude towards implementation of any concept. The organization needs to really see a value of implementing the concept in order to promote it and accelerate the implementation.

In contrast to the oil and gas department the project managers in the construction department are more knowledgeable about the information system and BIM. The result of this conclusion might not be representative for the industry in general neither for the organization since all of the interviewees work or have worked with BIM issues. On the other hand, what can be observed by talking with the different employees is that most of the people don't have a clear picture about BIM and its application. BIM is often referred to as a 3D model and the application and range of its use is not so well known. As mentioned in the theory in the definition of BIM, it should not be seen exclusively as a new technology but a new way of collaborating and performing construction projects consisting of interoperable technologies, integrated processes and collaborating people (Kimmance, 2002). A contributing reason why BIM is often referred solely to the 3D-model might be the name of BIM, which regards to Building Information Model or Modeling. In the manufacturing industry the information system is called PLM, Product Life-Cycle Management (Immonen & Saaksvuori, 2008). This makes it clear that it's a system that should impregnate the whole working process of an organization with the consideration of the whole life cycle of a project. However, it is not suggested to introduce a new concept with an even more acronym but more information about the methodology.

In general, it is clear that the organization is ambitious regarding the implementation of BIM and they have managed to increase the communication and collaboration towards other disciplines. A big step has been the introduction of BIM-meetings where the different disciplines gather for collision control and constructability check. This has led to fewer collisions on the construction site and has decreased total project cost (Arayici and Mihindu, 2008). Moreover, it can be seen how introduction of BIM and BIM-meetings move the organization towards a closer collaboration and Concurrent Engineering.

6 Conclusions

As mentioned in the background efficiency is one of the main issues the AEC-industry is struggling with and methodologies like CE and BIM were brought up as solutions to improve it. The benefits of CE and BIM derive from the fact that they are focused on the design phase of the project where much of the life-cycle economic and environmental costs associated with buildings are determined during this phase. By investigating and comparing the oil and gas industry with AEC industry this study shows that even the AEC companies have a lot to win with implementation of CE and BIM and they should take the step from exchanging information to exchanging knowledge.

RQ1: What are the benefits of BIM and CE in the AEC industry?
The research findings indicate that by implementing CE and BIM a design consultancy can gain fluent progress during the design phase by cutting the unnecessary waiting time between the decisions and actions. Furthermore, errors in the design will be decreased and thereby increase the quality of the projects. Using these methodologies brings the different disciplines together for optimizing the whole project life cycle. Efficiency of the industry is however not a driving force for a design consultancy firm, like the one studied in this report, to invest in new methodologies. However, customer satisfaction and competitive business that are the ultimate goals of BIM and CE should be reasonable driving forces for these companies to implement them. Introduction of CE might lead to some initial problems and requires extra expenses, more coordination time, encouragement of the client, own workers and other disciplines and stakeholders to commit to the methodology but having the ultimate goals in mind it can be well worth the effort.

RQ2: How can Concurrent Engineering be successfully introduced and implemented into the AEC-organizations?
The experience of the oil and gas industry contributes to several important issues regarding a successful implementation of CE and BIM. The research findings stress the importance of a dedicated leading board in order to support working in CE through all business processes and organizational structure. In order to implement CE successfully it is suggested that firstly the senior management should have a clear understanding of the CE and then inform everybody about the methodology and its application and thereby interest both own employees and the client. When the client is onboard and is aware of the benefits that they can get by CE everything else will come off naturally and hopefully the client will be paying for the extra expenses caused to the design consultancy.

This study proposes the organization to create a suitable interface for working in multidisciplinary teams and investment in special rooms and equipment. Furthermore, change agents are observed to be a vital element for implementation of CE and BIM. Project managers as a central part of a multidisciplinary teams should undertake the role of a facilitator in order to get the best out of everyone and create a good team confidence. A primary part of the introduction of CE is using pilot projects as a reference point and gaining experience not expecting everything will work well already from the start. Furthermore, internal learning process and continuous improvements are required after initial pilot projects.

The construction company in this study, like many other construction companies, works already in BIM meetings for discussing constructability issues. This kind of meeting could be a suitable platform for taking it further and develop it to CE work session. Another important lesson that can be taken from the oil and gas industry is that the AEC organization should not take the CE methodology by point but try to adjust it to fit its own work process in accordance with its own conditions. It is thus suggested to further research in the best practice of the CE methodologies within construction companies where question about duration of the meetings, how often they should work in CE work sessions, which participants should be presented, work session agenda etc. should be studied.

This study was limited to one single organization with its own working processes and organizational culture thus for a general understanding of CE and BIM benefits and their implementation issues there should be further research in this area with more organizations involved in the research. Furthermore, this study was limited to the use and implementation of CE and BIM during the design phase within a design consultancy and therefore for a holistic insight there should be further research about BIM and CE benefits during the construction and operation phase of a construction. Suggestions for further research would be to investigate how CE and BIM interfere the work of each discipline and how they can optimize their working process to actively participate and be part of a multidisciplinary team. Other research areas would be to investigate how to create a suitable environment for enhancing implementation of these methodology for instance what kind of contract form or organizational structure is the most suitable for introduction of these methodologies.

Two of the most important objective of these new methodologies were reduction of cost and time. This study could however not really confirm these two objectives due to uniqueness of each project within the construction industry and therefore there is a need for further research to develop measurement methods for calculating time and cost reduction.

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