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# Use of project execution models and BIM in oil and gas projects: searching for relevant improvements for construction

Doctoral Thesis

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# Summary

The oil and gas industry is characterized by large and complex projects and has invested heavily in the development of new technology. If the actors are going to compete in a global market and control project cost, time and quality, they are highly dependent on processes optimized for the management and execution of projects. Project execution models (PEM) have been introduced in the oil and gas industry as a means to improving the management and execution of major projects. A PEM offers a structured way of executing multidisciplinary work processes through all project phases. Building information modeling (BIM) is utilized in the coordination of complex projects and is part of the work processes defined in a PEM. This has been the basis for the first research question asked in this thesis: How are PEM and BIM utilized in major oil and gas projects in the cases studied?

The trend towards larger and more complex projects in the construction industry means that building owners, contractors and consultants are focusing on the professional management of projects, increasing interaction between project actors, and increasing exploitation of available technology. As part of this development, the construction industry would benefit from acquiring knowledge and learning from other relevant industries. Despite being two different industries, there are many similarities in project execution between the construction and oil and gas industries. The initial assumption of this research is that findings on project execution in the cases in the oil and gas industry can be relevant towards projects in the construction industry. This has been the basis for the second research question: How can experiences from the cases studied be relevant for improvements in construction projects?

The first research question has generated three main themes, while the second research question has generated a basis theme. The basis theme focuses on generalization and adaption of findings related to PEM and BIM from the oil and gas to the construction industry. The focus of main theme 1 is how changes in detail engineering can be managed using a change control system (CCS) and BIM. The focus of main theme 2 is how BIM can be used to report progress in detail engineering. The focus of main theme 3 is how a PEM and BIM can improve collaboration between engineering and construction in detail engineering.

A case study research method is used. Data is collected through interviews, document studies and observations. The data is analyzed using the stepwise-deductive-inductive (SDI) method. The cases are offshore projects in the oil and gas industry. I have accessed three ongoing projects – the topsides of the Eldfisk, Edvard Grieg and Johan Sverdrup offshore platforms, executed as engineering, procurement and construction (EPC) contracts, which are comparable to design-build contracts in the construction industry. In the first two, Kvaerner is the EPC contractor, focusing mainly on construction, and Aker Solutions an engineering and procurement subcontractor. The third is a joint venture between Kvaerner as EPC contractor and KBR as engineering and procurement contractor.

Research in the basis theme indicates that it is possible to generalize findings related to PEM and BIM through case studies. There are many similarities between the two industries, at both the industry and project levels, related to the two key concepts, PEM and BIM. This makes it highly relevant to adapt the findings from the case projects in the oil and gas industry to the construction industry.

The findings indicate that to succeed in project execution requires a focus on three dimensions – process, people and technology. This thesis presents findings in three main themes, related to these dimensions, which can be adapted to the construction industry and support improvements in project execution. In the interface between people and technology (main theme 1), a flowchart with describes the principles in a CCS, supported by a change management process, is developed. With this as a basis it is possible to adapt the principles and develop a system for managing and controlling design change requests for the construction industry. The main contribution to research from this part is the CCS flowchart, and the identification of four key features. These are the use of a Change Board for a holistic evaluation of change requests, the categorization of change requests – based on their cost and schedule impact – to allow more efficient processing, a formal client approval process, and the active use of BIM to assess if change requests are feasible and identify downstream consequences.

In the interface between process and technology (main theme 2), a three-step process for reporting progress in detail engineering with the use of BIM is developed. This process can be used as a basis for adaption to the construction industry. The main contribution to research from this part is the focus on detail engineering through the combination of the three steps. What further differentiates the three-step process from similar research is the first step, which is a prerequisite for the last two. In the first step, necessary preparations are made in building information models. Control objects, quality levels and status definitions are introduced, using principles defined in a PEM. In the second step, both visual and overall progress can be reported using BIM. By adding color codes to status definitions, progress can be reported visually, through control objects in the building information models. Overall progress can be reported, through aggregating the actual number of control objects and statuses on these, compared to an estimated number of control objects. By weighting the number of control objects, the calculation of the overall progress can be more accurate. To connect the overall progress towards an engineering schedule in the third step, activities in the engineering schedule are defined based on control objects, so that progress can be reported directly using BIM.

In the interface between process and people (main theme 3), a combination of three aspects increases collaboration between engineering and construction in detail engineering. Considering all three aspects is also the main contribution to research from this part, and can be used as a basis for adaption to the construction industry. The first, focusing on process, is

related to how the parts of the building information models that are frozen determines the degree of parallelism between engineering and construction, and how engineering can adapt a construction sequence using a PEM, by adjusting milestone requirements and delivering "right the first time". The second, focusing on people, is related to the transition from transactional to relational contracts, and selecting and developing the engineering team. The third, focusing on technology, is related to constructability and how an engineering contractor can split building information models in accordance with the requirements of the main contractor, to be able to define and control what is sent out for fabrication.

Further research will focus on adaption and potential implementation of the findings from the case projects in the oil and gas industry identified in the three main themes towards ongoing and upcoming projects in the construction industry.

# Acknowledgements

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# List of abbreviations

| | |
|---|---|
| BIM | Building information modeling (abbreviated BIM) |
| | Building information model (not abbreviated) |
| CAQDAS | Computer-assisted qualitative data analysis software |
| CCS | Change control system |
| DCR | Design change request |
| EPC | Engineering, procurement and construction |
| IDC | Interdisciplinary design control |
| IPD | Integrated Project Delivery |
| K2JV | Joint venture between KBR and Kvaerner at Johan Sverdrup |
| LCI | Lean Construction Institute |
| NDA | Non-disclosure agreement |
| PDM | Project Delivery Method |
| PEM | (a) Project execution model (general) |
| | (the) Project execution model (specific: Kvaerner/Aker Solutions) |
| PMBOK | Project Management Body of Knowledge |
| SDI | Stepwise-deductive-inductive method |
| VDC | Virtual design and construction |

# List of included papers

## Primary papers

### Paper 1

Mejlænder-Larsen, Ø. (2015). **Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry.** *Procedia Economics and Finance*, *21*, 271-278.

### Paper 2

Mejlænder-Larsen, Ø. (2017). **Using a change control system and building information modelling to manage change in design.** *Architectural Engineering and Design Management*, 13(1), 39-51.

### Paper 3

Mejlænder-Larsen, Ø. (2019). **A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects.** *Engineering, Construction and Architectural Management* (Accepted for publication 10 April 2018).

### Paper 4

Mejlænder-Larsen, Ø. (2018). **Improving collaboration between engineering and construction in detail engineering using a project execution model and BIM.** *Journal of Information Technology in Construction (ITCon)*, *23*(16), 324-339.

Secondary papers

### Paper 5

Mejlænder-Larsen, Ø. (2015). **Using a change control system and BIM to manage change requests in design.** *Proceedings of the 32nd International CIB W78 Conference*; 549-558.

### Paper 6

Mejlænder-Larsen, Ø. (2015). **Using BIM to follow up milestones in a project plan during the design phase.** *WIT Transactions on the Built Environment 2015;* Vol. 149, 97-106.

### Paper 7

Mejlænder-Larsen, Ø. (2016). **Improving transition from engineering to construction using a project execution model and BIM.** *Proceedings of the CIB World Building Congress 2016*; 1, 540-551.

### Paper 8

Mejlænder-Larsen, Ø., Flyen, C., & Lie, B. E. (2016). **Collaboration and BIM supportive project execution model for the construction industry.** *Proceedings of the 41st IAHS World Congress,* ISBN: 978-989-98949-4-5.

The author's contribution to Paper 8: Øystein Mejlænder-Larsen was the main author and responsible for the introduction (Chapter 1), part of the findings (3.1) and comparison to other industry initiatives (Chapter 4). Cecilie Flyen was responsible for the research method (Chapter 2), part of the findings (3.2), the discussion (Chapter 5) and conclusion (Chapter 6). These two authors worked in close collaboration on the discussion (Chapter 5) and conclusion (Chapter 6). Bjørn Erik Lie contributed to the findings (Chapter 3).

# 1 Introduction

Over the past 40 years, the oil and gas industry has focused on streamlining management and the execution of large and complex projects and invested heavily in the development of new technology. Complex projects are typically high-tech, capital-intensive, of a significant scale, long in duration, and require collaboration between actors in project delivery (Whyte *et al.* 2016). Among all regions, Europe has the highest number of oil and gas projects and most of them are located in the North Sea as offshore projects. These projects are much better controlled than those in other regions. Several advantages, such as high concentration of projects, practical experience of project teams, situational understanding, access to information, professionalism and competence, make project performance highly competitive (Rui *et al.* 2017). The Norwegian oil and gas industry was established in the late 1960s and has since evolved through an interaction between international oil companies, Norwegian suppliers, large R&D institutes (e.g. SINTEF) and universities, in addition to supportive policies such as R&D tax exemptions (Mäkitie *et al.* 2018). Furthermore, the Norwegian oil and gas industry has an international reputation for project management and active exploitation of technology (Sasson & Blomgren 2011). Long-term participation in development of technologies to support offshore oil and gas projects in the North Sea, has made the supply industry competitive - both in Norway and in international markets (Mäkitie *et al.* 2018). Through engineering, procurement and construction (EPC) contracts, which are comparable to design-build contracts in the construction industry, large and complex onshore and offshore projects in the 6-10 billion NOK range, are managed and executed. If the EPC contractor and engineering contractors are going to compete in a global market and control project cost, time and quality, they are highly dependent on processes optimized for the management and execution of projects.

In the construction industry, there is a trend towards larger and more complex projects (Fischer *et al.* 2017; Whyte *et al.* 2016). Larger projects, greater complexity and thereby increased risk means that there is a need for building owners, contractors and consultants to focus on improving processes related to the professional management of projects, on increasing interaction between project actors and the exploitation of available and innovative technology. Providing correct information to decision makers at the right time and on the right format is one of the most important ways to reduce waste in construction projects (Koskela *et al.* 2013). The Norwegian construction industry is highly decentralized, with many small companies and only a few large companies, and has challenges related to the need for more innovation and improved productivity, poor relationships between the construction parties and increasing competition from foreign companies on the domestic market. Innovation in construction companies is primarily related to how to plan and manage projects, how to organize the construction process, and how to handle clients and other counterparts (Bygballe & Ingemansson 2014). The industry is also under pressure to reduce project delivery times and costs, despite increased project complexity (Jaafari 1997; Bogus *et al.* 2005). Compared

to other industries, the construction industry has also been slow at technological development (WEF 2016), partly due to cultural resistance (Sarhan & Fox 2013).

As part of this development, the construction industry would benefit from acquiring knowledge and learning from other relevant industries, such as the oil and gas industry, with experience in the execution of large and complex projects (Rui *et al.* 2017). There is not, however, a tradition for doing so (Tuohy & Murphy 2015). Some of the best ideas for improving the engineering and construction process, such as Lean,[1] prefabrication, cross-functional teams, and building information modeling (BIM),[2] have been inspired by their application in other industries (Fischer *et al.* 2017). There are many similarities in project execution between the oil and gas and construction industries, including in the project phases, actors, management principles and use of technology. While rising oil price since the early 2000s has resulted in high profits and cost levels in the industry, the recent downturn in price has forced oil and gas companies to cut cost and consider diversification (Mäkitie *et al.* 2018). Despite that the oil price now has rebounded and the industry is recovering (Biscardini *et al.* 2018), the result of the recent downturn have been layoffs across the industry (WSJ 2017). Many talented individuals from all levels of oil and gas companies have moved over to other industries, including the construction industry. This has resulted in knowledge transfer from the oil and gas to the construction industry, which may have increased consciousness of the importance of optimized processes, supported by the active use of technology.

In this thesis I explore how a project execution model (PEM)[3] is used, in combination with the utilization of a 3D design environment,[4] which corresponds to BIM, in ongoing projects in the oil and gas industry. The use of a PEM was initiated to improve the management and execution of major oil and gas projects, with regards to risk, progress, quality and cost (AkerSolutions 2014b). This was supported by the increased use of a 3D design environment (hereinafter called BIM). A PEM is a generic breakdown of a project, and a structured way of managing and executing multidisciplinary work processes through all project phases (AkerSolutions 2014b). The PEM, as used in the case projects, cannot be fully utilized without the use of BIM, and is therefore also centrally involved in the work processes defined in the PEM, and is used in all project phases. In contrast to *a* PEM, which in this thesis is used to explain PEM in general terms, *the* PEM, refers to the PEM developed by Kvaerner and Aker Solutions. BIM is used in the coordination of complex projects, and to support management through enhanced

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[1] The idea of Lean is to "maximize value delivered to the customer while minimizing waste" (Shen *et al.* 2010: 204)

[2] Building information modeling (BIM) can be defined as "a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Succar *et al.* 2012: 120).

[3] A project execution model (PEM) defines a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones (Kvaerner 2012c)

[4] A 3D design environment is a multidisciplinary and object-based 3D design integrated with a number of information systems that serves as the main source of information (Kvaerner 2012a)

collaboration and information sharing (Bryde *et al.* 2013). In other words, embracing the use of BIM in projects offers advantages such as improved efficiency and collaboration by reducing the amount of re-work and early detection of potential problems, as well as improved management and communication of information generated by the building information models (Fakhimi *et al.* 2017). Many companies operate in siloed environments instead of encouraging a collaborative culture. Consequently, many of the key advantages of collaborative design using BIM remain unexplored (Merschbrock & Munkvold 2015). The benefits of BIM can be reinforced if opportunities related to new ways of collaborating and sharing information among actors are exploited (WEF 2016).

I have assessed how three major offshore projects in the oil and gas industry are executed through Kvaerner,[5] a Norwegian EPC contractor, Aker Solutions,[6] a Norwegian engineering contractor, and KBR,[7] an American engineering contractor. The projects used as cases are Eldfisk, Edvard Grieg and Johan Sverdrup. These are all topsides of offshore production platforms in the North Sea, mainly consisting of the living quarters and utility module. The initial assumption of this research is that relevant findings on project execution from projects in the oil and gas industry can be adapted to the construction industry and support improvements in project execution.

## 1.1 Aim and research questions

The aim of this article-based thesis has been divided in two. The first has been to contribute knowledge on the use of a PEM combined with the use of BIM in major oil and gas projects. The second has been to assess if this knowledge can support improvements in construction projects. This has been achieved by asking the following research questions: How are PEM and BIM utilized in major oil and gas projects in the cases studied? How can experiences from the cases studied be relevant for improvements in construction projects? The research questions are based on the notion that the construction industry can benefit from looking to how the oil and gas industry has executed large and complex projects with the use of PEM and BIM, to support improvements in project execution. The research questions can be split into two parts (see Figure 1 below).

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[5] Kvaerner is the largest specialized EPC company in Norway. See http://www.kvaerner.com/About-us/Who-we-are-and-what-we-do/ (Accessed 23.06.2017)
[6] Aker Solutions is one of Norway's largest provider of products, systems and services to the oil and gas industry. See http://akersolutions.com/who-we-are/ (Accessed 23.06.2017)
[7] KBR is a large international contractor. The American-based company is a global provider of services and technologies related to the oil and gas industry. See https://www.kbr.com/pages/Who-We-Are.aspx (Accessed 23.06.2017)
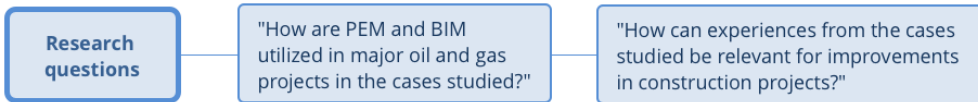
*Figure 1: Research questions in two parts*

The first part of the research question emphasizes that the research is based on experiences from major projects in the oil and gas industry, executed as EPC contracts. The focus is how the use of a PEM and BIM are utilized in the case projects. The second part of the research question asks how experiences from the case projects can be relevant for improvements in projects in the construction industry. Projects in this context are mainly executed as design-build contracts, with a focus on the detail engineering phase (hereinafter called detail engineering) and the transition to the construction phase (hereinafter called construction). The use of a PEM and utilization of BIM are two key concepts that constitute the focus and scope for the research, and the basis for the main findings. Similarities between the oil and gas and construction industries, in particular in terms of project execution, are a prerequisite for the relevance of the findings towards the construction industry.

## 1.2 Research themes and motivation

The findings of the research are structured and presented through a basis theme and three main themes, with corresponding focus areas (see Figure 2 below). The basis theme was selected to assess if the construction industry had sufficient similarities with the oil and gas industry in terms of project execution, and, therefore, if the findings from the projects used as cases (case projects) in the oil and gas industry could be applicable to the construction industry. The main themes were selected based on their criticality to project execution in the case projects and relevance to the construction industry.
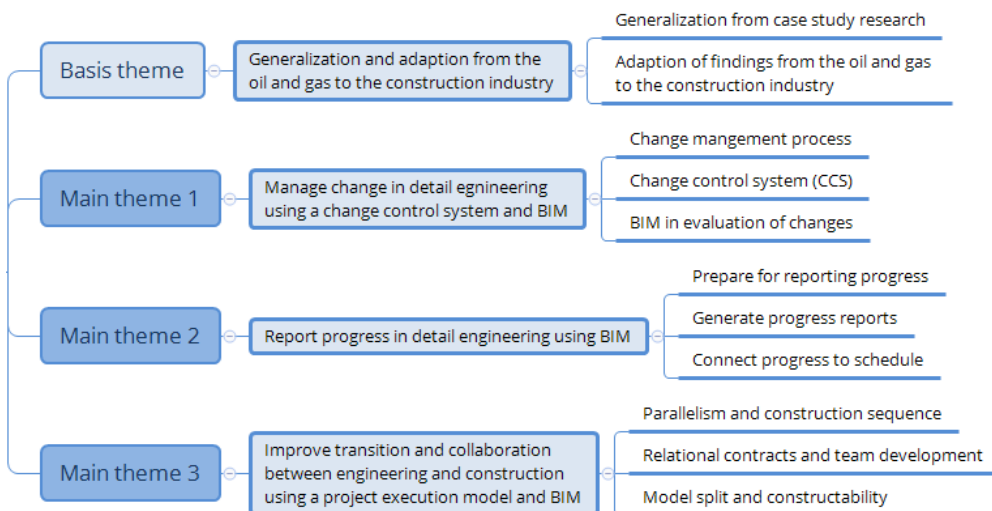


*Figure 2: Research themes with focus areas*

The focus of the basis theme is the generalization of findings from projects in the oil and gas industry and possible adaption to the construction industry. It comprises two parts. The first part examines the possibility of generalizing findings using case study research. The second part explores if project findings related to a PEM and BIM can be adapted to the construction industry.

The focus of main theme 1 is how a change management process, supported by the use of a change control system (CCS), can be used for managing design changes in larger multidisciplinary projects. It comprises three parts. The first part defines a change management process. Based on this, the second part describes the principles of a CCS and how it is applied in detail engineering. The third part describes how BIM can be used to identify the impact and consequences of changes in detail engineering.

The focus of main theme 2 is to assess how BIM can be used in detail engineering to report progress and connect to activities in an engineering schedule. It comprises three parts. The first part introduces the necessary preparations for reporting progress from building information models.[8] The second part focuses on how progress data from the building information models can be extracted, visualized and used in progress reports. The third part focuses on how reported progress from building information models can be connected to an engineering schedule to report progress on activities.

The focus of main theme 3 is collaboration between engineering and construction in detail engineering. It comprises three parts. The first part is concerned with parallelism between engineering and construction, and delivering according to a construction sequence through milestone requirements. The second part focuses on relational contracts and engineering team development. The third part looks at how engineering deliverables must be adapted to fabrication needs.

These themes were not selected prior to commencing data collection. I began interviewing key informants from Kvaerner with a focus on the two key concepts – PEM and BIM. Doing so allowed me to get a more in-depth insight into their use (both alone and combined) and how they were applied in the case projects. It also meant I could avoid setting strict guidelines for the interviews, and instead explore possible themes, based on what the informants considered to be relevant and important aspects related to the use of a PEM and utilization of BIM. The research themes were then selected based on the empirical data from the first

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[8] A building information model can be defined as an "accurate virtual model of a building constructed digitally [that] when completed […] contains precise geometry and relevant data needed to support the design, procurement, fabrication and construction activities needed to realize the building" (Eastman *et al.* 2008: 1).

seven interviews (four with the main focus on the PEM and three with the main focus on BIM), complemented with relevant company and project documents, and field observations.

The motivation for main theme 1 is that project changes occur at all stages of detail engineering and construction, with decisions that often have to be made based on incomplete information, assumptions and the experiences of individuals (Shen *et al.* 2010). Early in the design process, everything changes because there is naturally a conceptual development period during which various concepts and alternative solutions are developed and evaluated. In detail engineering, the design should be gradually frozen. When frozen, the shape and location of objects in a building information model, and all interfaces towards other objects and disciplines in the relevant parts of the building information model should, by definition, not be changed. Engineering teams may implement changes in detail engineering without fully understanding the potential impact on the cost and schedule of the project, or the effect on contractual requirements, as specified by the client. According to Isaac & Navon (2009), this is because the tools currently used for project planning and building design are not able to evaluate the consequences of a specific change before the plan and building design are fully updated. As a result, deviations from client objectives, caused by changes in the project, are often revealed late in the project or after its completion. This could be solved by introducing a change management process and a corresponding system targeted towards major projects in the construction industry.

The motivation for main theme 2 is that the primary focus in the research related to progress management is on construction and not engineering (Matthews *et al.* 2015; Sacks *et al.* 2009). There is also a need for interoperability between BIM and scheduling software in detail engineering (Kim *et al.* 2013b). Research related to the construction industry shows that progress can be related to modeling objects (e.g. walls, slabs, columns, beams) in building information models. Object statuses have been introduced to identify when certain quality levels have been reached. The reason is to move away from estimates, sometimes guesstimates, on how far each discipline has come when reporting progress. This is why it is important that progress data can be extracted directly from the building information models and connected to an engineering schedule.

The motivation for main theme 3 is the challenges related to the fact that engineering and construction are not currently well integrated in the construction industry (Luth *et al.* 2013). Usually engineering takes place over a given period of time, followed by construction. Demands for shorter execution times mean there is a need for construction to be pushed forward and happen in parallel with engineering. The engineering consultant prefer to think of the design as a whole until detail engineering is finished, while the main contractor will follow a construction sequence that is cost effective for them. According to Berard & Karlshoej (2012), the influence and inclusion of main contractors in detail engineering is important because main contractors can then receive deliverables suited to their construction method.

This calls for increased focus on collaboration between engineering and construction in detail engineering.

## 1.3 Scope and limitations

The scope of the thesis comprises five dimensions (see Figure 3 below). The first is type of industry. The second is key actors. The third is key concepts. The fourth is the project level, and includes project type and size, type of project contract and project phase. The fifth is execution level. In the figure, "Source and main scope" is related to key characteristics of the cases in the oil and gas industry used as a basis for the research, and "Relevant target" is related to key characteristics of projects in the construction industry where the results from the research can have relevance.
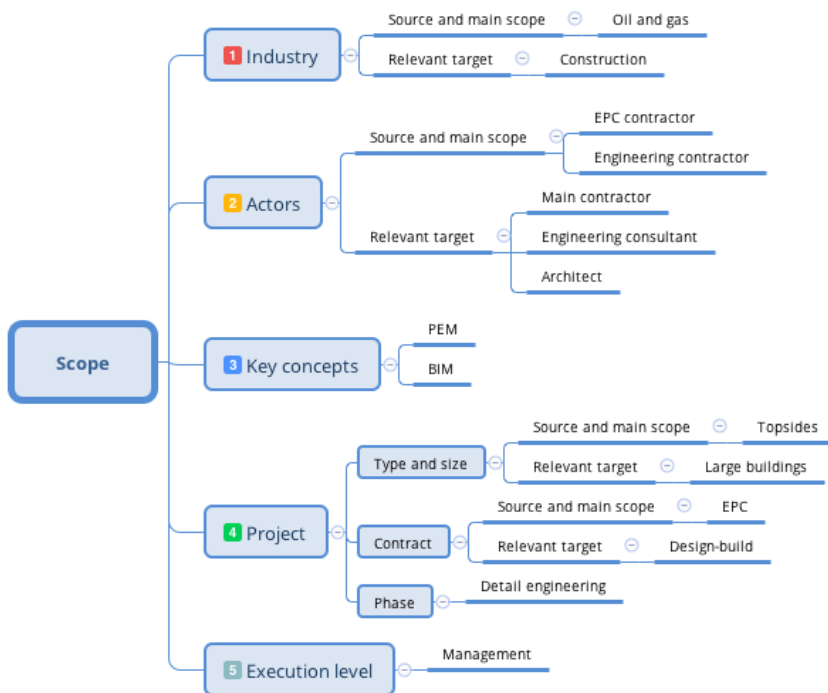


*Figure 3: Research scope in five dimensions*

The source and main scope is the oil and gas industry. All empirical data has been gathered from three ongoing projects, through an EPC contractor, Kvaerner, and two engineering contractors, Aker Solutions and KBR. These companies compete in a global market. They have therefore adapted their way of executing projects to allow them to do so. Selecting case projects from other similar EPC contractors or engineering contractors might have given slightly different results, especially related to the structure of the PEM, and the degree of utilization of BIM. The relevant target for the research findings is the construction industry. Actors are primarily main contractors (and subcontractors) and engineering consultants, as

well as architects. Despite having included architects, I have focused on the principal and more linear processes rather than the creative and iterative processes involved in detail engineering.

Transfer of knowledge does not only work in one direction; rather than having projects in the oil and gas industry as the source and main scope, and the construction industry as the relevant target, I could have focused on projects in the construction industry and potential learnings towards the oil and gas industry. A comparison between the two industries are made as part of the basis theme, but as the main scope is projects in the oil and gas industry, I have not completed a comprehensive review of the similarities and differences between them. Furthermore, I have focused on the relevance of the findings and not focused on learning and transfer of experience as separate phenomena, nor the implementation of new methods or tools and the handling of resulting changes. The use of PEM and utilization of BIM are key concepts. The initial research uncovered that compared to the detailing level and comprehensive use of PEM in projects in the oil and gas industry, the use of a PEM in the construction industry is limited. In this thesis, the use of BIM is primarily in combination with, or related to, the use of a PEM. Relevant research on BIM has been elaborated as part of the three main themes. Because the scope of the research is towards projects in the oil and gas industry, the development of BIM in the construction industry and experiences and results related to this, and how the utilization on BIM could be adapted from projects in the construction industry to the oil and gas industry, have not been elaborated.

Three projects in the oil and gas industry are used as cases in the research. Expanding the number of case projects might have given more nuanced results, however, more cases would have meant much more time spent collecting and analyzing the empirical data, or more superficial research towards each case, which would not have been achievable or desirable in this doctoral research project. The case projects – Eldfisk, Edvard Grieg and Johan Sverdrup – are executed as EPC contracts, with Kvaerner as EPC contractor, focusing mainly on construction, Aker Solutions as engineering and procurement subcontractor, and KBR as engineering and procurement contractor. EPC contracts in oil and gas projects are comparable to design-build contracts in the construction industry. The projects, and especially the living quarters on the topsides, have similar characteristics to relevant target projects in the construction industry, which are mainly large, complex projects, such as residential, governmental, healthcare, educational, industrial and commercial buildings.

I have not tested the findings from the case projects on construction projects as part of this thesis. Through the Norwegian research project "Collaboration in the building process – with BIM as a catalyst" (Bråthen *et al.* 2016), known by the abbreviation SamBIM, on which I have participated as one of two PhD candidates, I have had access to several projects in the construction industry. This includes the projects used as cases by my fellow PhD candidate (Bråthen 2017: 23). It could have been highly relevant to use these as additional case projects

in the research, so that project findings could have been compared and used as a basis for adaption and possible implementation from the oil and gas industry to the construction industry. However, doing so would have meant less time available for research on projects in the oil and gas industry, making it difficult to go into sufficient depth on these. Whether the findings in the main themes will have a similar outcome in large, complex construction projects, is yet to be investigated. This has been outlined as a recommendation for further research (see 5.4).

The primary focus has been on detail engineering. There are several reasons for this. An initial literature review revealed that previous studies have tended to focus on construction more so than detail engineering. Additionally, my background and work experience are related to engineering, mainly in the construction industry. Multiconsult, my employer and the main financial contributor to this thesis, is one of the largest engineering consultants in Norway, serving several industries, including oil and gas and construction. The three case projects were all in detail engineering when appointed to me. The main target audience is at the management level, even though the level of abstraction of the research varies and includes both management and execution principles. The vast majority of the informants interviewed are also at the management level.

Based on the empirical data from the initial interviews, other research topics were also relevant to explore, but not selected. The first potential topic was industrialization of the construction process through prefabrication, which covers a range of methods and approaches to increase the efficiency and productivity (Økland *et al.* 2018). It is often associated with prefabrication and modularization (Gibb 2001), motivated by shortened construction time, reduced costs, better work quality and less environmental impacts (Molavi & Barral 2016; Bygballe & Ingemansson 2014). Industrialization of the construction process is not only about standardization of building components and building types, but also closely connected to standardization in work processes (Larsson *et al.* 2014). Prefabrication is common in oil and gas projects, either through in-house fabrication facilities or outsourced to fabrication subcontractors. Prefabrication can increase construction efficiency by enabling better sequencing in the construction process, and thereby reduce project delivery time and construction cost (WEF 2016). This topic was not selected because the focus of the research is mainly on detail engineering, not construction. The second potential topic was project organizations, and in particular roles, responsibilities and communication lines. This was not selected because of the focus on themes directly related to the use of a PEM and BIM. Selecting and developing a project team has been elaborated as part of main theme 3, but not how the team is organized. The last potential topic was outsourcing of engineering deliverables to low-cost countries. Deliverables can either be outsourced to external parties, or to subsidiaries in low-cost countries. This was not selected because of the resources needed. Outsourcing requires a particular infrastructure that many companies do not possess, which therefore reduces the potential for a broader relevance to the construction industry.

The work in this thesis is based on an industrial PhD scheme,[9] in which the PhD candidate is a company employee and at the same time admitted to a doctoral degree program at a university. The benefit for my employer, Multiconsult,[10] is that they have been involved in defining the scope and selecting relevant themes for the thesis. Through an appointed internal supervisor, Multiconsult has been in a unique position to follow up and guide me, as a candidate, throughout the research process. The goal has been to conduct research that can be relevant and adaptable to the construction industry, and at the same time applicable to projects in Multiconsult.

## 1.4    Relationship between research questions, themes and papers

This article-based thesis includes four primary papers (Papers 1, 2, 3, and 4), and four secondary papers (Papers 5, 6, 7, and 8). The first research question (How are PEM and BIM utilized in major oil and gas projects in the cases studied?), has been answered through the three main themes. Each of these is covered in a primary paper, which builds on a secondary paper. The second research question (How can experiences from the cases studied be relevant for improvements in construction projects?), has been answered through the basis theme, which is covered in a primary paper. This is illustrated in Figure 4 below, where green represents journal articles, orange represents conference papers published in journals, and blue represents conference papers.
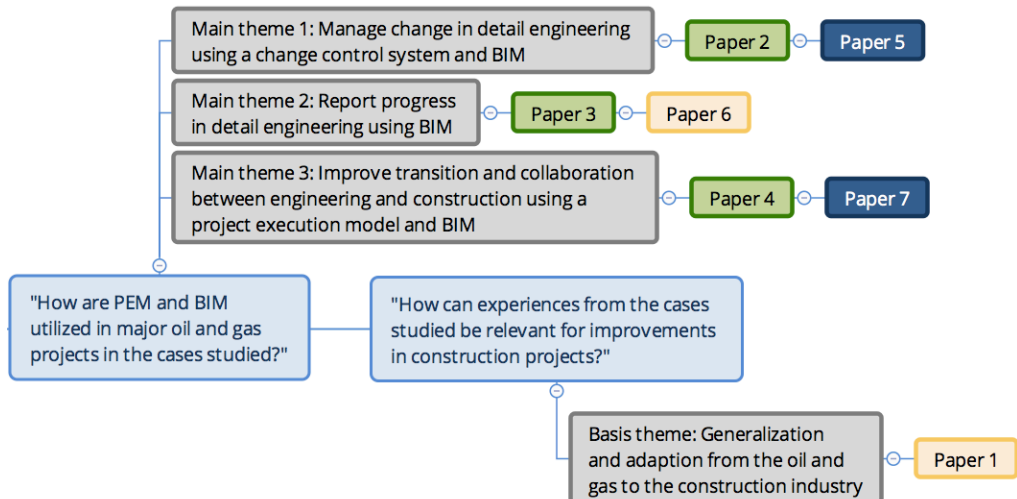


*Figure 4: Relationship between research questions, themes and papers*

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The basis theme is covered in Paper 1, "Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry", which is a conference paper published in a journal.

Main theme 1 is covered in Paper 2, "Using a change control system and building information modeling to manage change in design", which is a journal article. Paper 2 is developed from Paper 5, "Using a change control system and BIM to manage change requests in design", which is a conference paper.

Main theme 2 is covered in Paper 3, "A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects", which is a journal article (accepted for publication 10 April 2018). Paper 3 is developed from Paper 6, "Using BIM to follow up milestones in a project plan during the design phase", which is a conference paper published in a journal.

Main theme 3 is covered in Paper 4, "Improving collaboration between engineering and construction in detail engineering using a project execution model and BIM", which is a journal article. Paper 4 is developed from Paper 7, "Improving transition from engineering to construction using a project execution model and BIM", which is a conference paper.

As part of the SamBIM research project, a framework for a PEM has been developed for the construction industry. In the framework, based on input from the SamBIM partners, potential benefits of BIM are identified. This is addressed in Paper 8 "Collaboration and BIM supportive project execution model for the construction industry", which is a conference paper developed through the SamBIM research project. Paper 8 support the second research question.

## 1.5   Structure of the thesis

This chapter has presented the context and motivation for the thesis, the research questions, the research topics and motivation, the choice of themes, the scope, and the relationship between the research questions, themes and papers. The second chapter, entitled Frame of references, introduces the concepts of PEM and BIM and discusses these in relation to relevant research. The third chapter, Research design, describes the case study research method, explains how the cases were selected, how the data were collected and analyzed, and how the quality of the research design has been ensured. The fourth chapter, Presentation of papers, introduces the four primary papers and the four secondary papers. The fifth chapter, Discussion and conclusions, identifies the coherence between the themes, presents the main findings of the papers and how these addresses the research questions. The research is then summarized, main contributions are identified, and recommendations are made for further research. Appendix A includes an example of an interview guide. Appendix B includes the four primary papers and the four secondary papers.

## 2 Frame of reference

The frame of reference has been divided in two main parts; BIM and PEM, which correlates to the two key concepts. The frame of reference is therefore limited to the concepts that are central to the later discussions. PEM and BIM have been the basis for the selection and scope of the basis theme and the three main themes. These are central to the first research question and have been the starting point for the second research question. The two key concepts are therefore defined and discussed in relation to the research field. The theory I have focused on here is important in order to discuss the findings and put them into a larger context while at the same time show how they fill a knowledge gap. There are also theory sections in each paper that complements the theory in this chapter.

BIM, as a term, has several definitions, is widely used in research, and is applied across a broad range of areas. The first part on BIM therefore briefly introduces BIM as a term, and how it is used in the case projects in the oil and gas industry, compared to the construction industry (2.1). Important developments in BIM in the three main themes, related to change management (2.1.1), progress management (2.1.2) and collaboration between engineering and construction (2.1.3), are identified.

The second part on PEM introduces PEM as a term (2.2). As a background, relevant perspectives related to project management have been briefly introduced, followed by an introduction to knowledge management (2.2.1). With this as a basis, the three levels of the PEM – strategic, control and execution (Kvaerner 2013b), the relationships between these, and how it is used in the three main themes, are elaborated and compared to other relevant models and methods. In addition, how BIM is a vital part of the PEM, especially at the execution level, is discussed (2.2.2).

It has been important to look at PEM and BIM in combination. The first two levels of the PEM can be used without BIM, and BIM can be used without a PEM. However, to fully exploit the possibilities of the PEM requires the use of BIM, especially on the execution level, and the use of a PEM will streamline and further enhance the use of BIM. The combination of these therefore generate knowledge that I would not have gained by looking at them individually.

### 2.1 BIM

In this thesis, BIM is used as an acronym for building information modeling, as a process, while building information model is used to describe a virtual model. In other words, BIM refer to the processes of modeling, collaboration and integration and building information model refer to the object-based model (Sun *et al.* 2017). Similarly, BIM, as used in the construction industry, is an acronym for both building information modeling, as a process, and building information model, as a virtual representation of a building. Put another way, the result of

building information modeling (BIM) activity is a building information model (Sacks *et al.* 2010a). BIM not only means using building information models but also making significant changes to the workflow and project delivery processes (Azhar *et al.* 2012). BIM was introduced to the construction industry to improve efficiency, reduce costs and as an overall support to management during all stages of construction. BIM has changed how projects are planned, designed and produced (Bygballe & Ingemansson 2014). Using BIM can enhance collaboration between actors and increase productivity in the construction industry, as well as improve design and construction practices. (Ghaffarianhoseini *et al.* 2017).

Some of the key aspects required for being able to deliver complex projects are better integration and cooperation, in addition to coordination of project teams. To support this, BIM not only contributes to cost reduction, time reduction and quality increase, but also to better integration, cooperation and coordination (Bryde *et al.* 2013). BIM software also provide optimized platforms for parametric modelling, enabling new levels of spatial visualization, building behavior simulation, effective project management and operational collaboration (Nepal & Staub-French 2016). In addition, numerous research articles identify existing and potential utilization of BIM in construction projects. Among those relevant as a backdrop for this thesis, Sacks *et al.* (2010a) identify BIM functionality, while Azhar (2011) underlines the applications and benefits of BIM, and Bryde *et al.* (2013) identify benefits of BIM for project management.

Another term that is used in parallel with BIM in the construction industry is Virtual Design and Construction (VDC),[11] which extends the scope of BIM. VDC emphasizes those aspects that can be managed, as well as those that can be designed (Kunz & Fischer 2012). In contrast to BIM, VDC includes not only the product, but also the organization and work processes (Fischer *et al.* 2017). The product is typically a facility or the components and systems of the building. The organization designs and constructs the facility. The process relates to activities and milestones for the stakeholders (Kunz & Fischer 2012). BIM has been used as a term in the doctoral thesis. The extended focus on organization and work processes are reflected through the focus and use of a PEM, in addition to utilization of BIM.

The uses of BIM differ somewhat between the case projects in the oil and gas industry and the construction industry. The size and complexity of the building information models, and the amount of information related to each modelling object, are much greater in the case projects. A multidisciplinary aggregation of building information models are not supported by the BIM software used by the engineering team in the case projects, as a result of the complexity of the building information models and the amount of information attached to each modelling object. As a result, many connected support systems, which works as external

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[11] Virtual Design and Construction (VDC) is "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives" (Kunz & Fischer 2012: 1).

databases, are used to process the large amount of information. Most of the information is stored in the corresponding support systems, rather than the modeling objects themselves, and connected to the modeling objects via unique tag numbers (Kvaerner 2012a). In the construction industry, on the other hand, the BIM software used by the engineering team can assemble the building information models of all disciplines. All relevant information is contained within each modeling object in the building information models. In other words, BIM has developed to facilitate the increasing complexity of construction projects (Ghaffarianhoseini *et al.* 2017).

Data exchange standards have been developed in order to fully enable collaboration using BIM, which enables and systematizes interoperability (Nepal & Staub-French 2016). In the case projects in the oil and gas industry, the exchange of building information models within and between disciplines, and between different BIM software, are based on proprietary formats. This limits the interoperability between different software, and thereby limits the choice of BIM software and the exchange of building information models between actors and disciplines in a project. In contrast, the construction industry has focused on interoperability and standards for open and non-proprietary formats, such as Industry Foundation Classes (IFC), developed by buildingSMART,[12] to support the exchange of building information models within and between disciplines and between different BIM-based software.

### 2.1.1   Change management

Change management is about managing changes in a project. According to Sun et al. (2006), the objective of change management is to anticipate possible changes, identify changes that have already occurred, plan preventive impacts and coordinate changes across the entire project. Similarly, change management can be defined as an overall work process that includes the proactive measures required to reduce the volume of changes, and to ensure that the cost, schedule and quality are under control (AkerKvaerner 2005). Streamlining the change management process can reduce the time and cost of processing change orders (Du *et al.* 2015). This is in contrast to operational and strategic changes in an organization, which is not part of the scope of the doctoral thesis. According to Todnem By (2005) organizational change management is the process of continuously renewing the direction, structure, and capabilities of an organization to serve the changing needs of external and internal customers.

One of the most effective methods to deal with change is to develop an efficient change management system (Zhao *et al.* 2009). There have been several attempts to create change management systems. Among these, Sun *et al.* (2006) presented a change management toolkit, to support their change management process model. The tool relies on extensive user inputs of project characteristics, which makes it difficult to use in practice. Similarly, Motawa

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[12] See http://www.buildingsmart.org/ (Accessed 10.10.2017)

*et al.* (2007) presented an integrated change management system, to support their change process model. According to the authors, significant effort is needed to ensure a proper implementation, and additional research is required to validate the effectiveness of the system.

BIM is used as part of evaluating changes. When changes are detected, it can be difficult to identify all consequences. Engineering teams often rely on subjective expert opinions, manual analyses and comparisons of drawings, due to the lack of competence and use of BIM software to track and present changes between different versions (Pilehchian *et al.* 2015). If proper BIM-based review software is used, changes will most likely be identified in time and not end up as clashes that need to be resolved. The cost of changes increases towards the end of detail engineering, when the building information models are completed and released for construction. At the same time, the ability to impact costs and schedule decreases. Using BIM increases detailing of the design earlier in detail engineering, which gives a better basis for evaluating the consequences of changes while the cost of changes remains low and the ability to impact costs and schedule remains high.

### 2.1.2 Progress management

In research on progress management with the use of BIM in the construction industry, there has been very little focus on the use of object status. According to Sacks *et al.* (2009), visualization of status is needed and should be displayed in a manner that can be readily understood by all actors involved in a construction project, regardless of their technical knowledge. Sacks *et al.* (2010b) defined the state of readiness of a work package or a task, measured through maturity. The maturity index was displayed using color-coded symbols on task icons. Chen & Luo (2014) describe how building information models can visualize quality status in construction with different color codes, grouped as before or after inspection was performed. The primary focus in these and similar research have been on construction, and not detail engineering. The main focus in research on BIM and progress is related to 4D, where objects are linked to a construction schedule, and time represents the fourth dimension. The concept of 4D, for construction process visualizations, has been adopted in the construction industry (Hartmann *et al.* 2012) and several commercial software are available for 4D construction planning (Sacks *et al.* 2009). Later developments, such as synchronization and comparison of data between BIM and on-site real-time progress through methods and technologies based on laser scanning (Han & Golparvar-Fard 2017), radio frequency identification (RFID), augmented reality (AR) (Golparvar-Fard *et al.* 2012; Matthews *et al.* 2015) and geographic information systems (GIS), have been introduced for planning and monitoring construction (Sun *et al.* 2017). When it comes to research on progress management in construction, Kim *et al.* (2013a) proposed a new method for measuring construction progress with a 4D BIM and 3D data. Matthews *et al.* (2015) examined how a cloud-based BIM software could be used during construction to provide real time progress

monitoring and improve decision-making. Bosché *et al.* (2015) presented a method for progress tracking of MEP components with an automated comparison of as-built and as-planned, through as-built laser scans and as-designed BIM models. Common among these and similar research on progress management is the primary focus on construction, and not detail engineering.

When it comes to detail engineering, there is a need for enhanced interoperability between BIM and scheduling software (Kim *et al.* 2013b). Previous research has indicated that it is possible to report progress by generating activities in a schedule based on BIM, although the primary focus has been on construction. Among these, Kim et al. (2013b) generated a simplified construction schedule using BIM with a limited number of basic building components, by creating construction tasks, calculate activity durations using productivity rates and applying sequencing rules.

### 2.1.3 Collaboration between engineering and construction

With parallelism, a project is executed in phases, but engineering and construction are overlapped to save time (Jaafari 1997). According to Lee et al. (2005), concurrent engineering and construction, has gained popularity due to the increased demand for shorter time frame of projects. Parallelism involves grouping deliverables into work packages so that construction can start before engineering is complete (Bogus *et al.* 2011). This is similar to what Succar (2009) has defined as "BIM stage 2", where engineering and construction is in parallel, and is driven by construction providing design-related services, and engineering increasingly adding construction and procurement information into their building information models.

It is important to be aligned in the sense that there is a correlation between how engineering is conducted and the planned construction sequence. Normal practice is to produce a design based on no particular construction sequence (Luth *et al.* 2013). In many circumstances, building information models created by the engineering team therefore do not meet the needs of contractors, as they are meant towards developing the design and producing construction drawings. Contractors often end up having to recreate the building information models because the building information models and corresponding content that they get from the engineering team are often incomplete, inaccurate, and ill-defined in scope (Nepal & Staub-French 2016). To achieve improvements in construction productivity, the actors must ensure that the actual construction process is kept in mind during engineering (WEF 2016). To deliver according to a desired construction sequence, require focus on "right the first time", which is delivering the necessary information right the first time and thereby reducing the amount of rework (Pheng Low & Yeo 1998). It means that the fabrication order can be determined logically as an integrated part of the design process. Knowledge on construction sequences, methods and means can be incorporated into the building information models, in order to reach a sufficient quality level to produce deliverables for construction (Luth *et al.* 2013). Not including construction knowledge in the design will likely lengthen the project

duration and make it more expensive because time and effort are required for redesign or for inefficient construction (Fischer *et al.* 2017).

The main distinction between different contractual agreements are related to contractual relationship and organizational structure (Mesa *et al.* 2016). The former defines the contractual responsibilities, risk allocation, and the form of compensation methods for selecting participants. The latter defines how the participants communicate and report to each other. According to AIA (2007), traditional contracts often create boundaries that rarely overlap, with clearly defined responsibilities for the parties in a project, and consequences if failures are made. Current contractual arrangements, rather than reinforcing the need to bring the members of the project team together to create innovate solutions, drive them apart to work in independent silos (Fischer *et al.* 2017). The focus is on transaction between the parties. Relational contracts on the other hand, focus on the relationships that are necessary for successful execution and completion of a project. Matthews & Howell (2005) states that relational contracts minimizes transactional costs because the parties are bind together in a partnership through the whole project.

## 2.2 PEM

A project execution model (PEM) is not a model per se, but a standard methodology used in all projects within an organization, and the documented experience of how to execute and deliver projects (AkerSolutions 2014b). According to Packendorff (1995), most methods for project planning and control are basically about finding the optimal sequence of activities and corresponding resource allocation. A PEM helps the project team to execute and complete activities at the right time and in the right sequence (Kvaerner 2012c). Projects are often executed by project teams that are demobilized when the projects are finished. The knowledge that is obtained by the project participants through engineering and construction is then dispersed across project teams (Deshpande *et al.* 2014). Each project participant has their own set of expectations and experiences which they carry with them into the team. These may be aligned with the other participants to a greater or lesser extent (Lundin & Söderholm 1995). The objective of a PEM is to secure predictability in project execution using a standard methodology well known to the project team, with a focus on safety, quality and cost efficiency, and to ensure multidisciplinary understanding, focus on common goals, and avoid rework by delivering "right the first time" (Kvaerner 2012c).

According to Lundin & Söderholm (1995), the period of time or duration of a project, should be split in sequences, as consecutive phases, from start to termination. The phases indicate actions which are desirable, through activities. The idea is to have a set of key activities that have to be handled in different phases of a project. The work processes in a PEM should cover all main project phases through a framework based on a typical project size and complexity.

It must be tailored to the needs and distinctive characteristics of each project. A PEM must be used by everyone in the company that are involved in management or execution of projects.

### 2.2.1   Background

A PEM is a framework for developing and sharing best practice in the company and thus a basis for continuous improvement. As a background to the development of a PEM, I have reflected on relevant developments in project management. Starting from extending the scope of a project as more than a lonely phenomenon, through different perspectives on project management and the shift towards social processes. This is concluded with introduction of two different perspectives on project management, the task and the organizational perspective. Also, as a background to the development of a PEM, I have reflected on relevant perspectives in knowledge management. Project knowledge is often not captured and used on future projects. To counteract this requires focus on the shift from tacit to explicit knowledge, which can be supported by knowledge management. The use of a PEM reflects a focus on the task perspective on project management and is based on principles of knowledge management.

#### 2.2.1.1   *Project management*

According to Engwall (2003), research on project management has been dominated by a perspective on the project being defined as a lonely phenomenon, independent of history, contemporary context and future. Instead of a lonely and closed system, the project should be seen as an open system. Success will primarily depend on the skills of the project management related to systematic planning, the right composition of the project team, and the application of project management techniques and procedures. The assumption is that the qualities of a project, as described in collections of project management knowledge, such as the Project Management Body of Knowledge (PMBOK) (PMI 2013), is applicable to all sorts of projects in all sorts of industries. Because the project has been defined as a lonely phenomenon, procedures and techniques applied in project execution have rarely been related to surrounding organizational structures and routines. The research suggest that the exploitation of existing knowledge and repetitions of existing procedures would produce predictability.

There have been established different project management schools which focus on different aspects of project management and corresponding approaches and methods (Andersen 2016). Packendorff (1995) presented the idea of different perspectives on project management and introduced the shift from focusing on the project as a tool to a temporary organization. This means a shift from traditional concepts such as planning and structure, towards social interaction, and from the perspective of the "user" to the focus on several perspectives. The UK-based research network Rethinking Project Management proposed a new view on project management, where projects should focus on project complexity, social

processes, value creation, adopt a broader conceptualization, and encourage practitioner development. Similarly, "Making Projects Critical", is the title of a series of international workshops, where the theoretical and methodological limitations of traditional conceptions of projects and project management have been highlighted (Andersen 2016). According to Cicmil *et al.* (2006), PMBOK has emphasized the role of project actors and managers as focusing on control and content, instead of a wider potential towards the role as social actors. The authors claim that the understanding of project actuality, through a focus on social processes, will contribute to better outcomes in ongoing projects. Project actuality is the understanding of experiences of project members, with the assumption that projects are complex social settings with tensions between project participants.

According to Andersen (2016) there are two different perspectives on project management, the task and the organizational perspective. In the task perspective, a project can be defined as making a unique product where the main focus is delivering on time, within budget and according to a specified quality. PMBOK, where a project is defined as "a temporary endeavor undertaken to create a unique product, service, or result" (PMI 2013: 3), reflects the task perspective. The project objectives are defined at start and expressed by time, cost, and quality. To minimize the time, relevant subtasks can be executed in parallel when possible. The organizational perspective is an alternative perspective on project management. Here, a project is a temporary organization, established by its base organization to carry out an assignment on its behalf. This perspective, introduced by Lundin & Söderholm (1995) and Packendorff (1995), has been called the Scandinavian School of Project Management. While Lundin & Söderholm (1995) focus on the interplay between the permanent organization and the temporary organization, Packendorff (1995) focus on the shift from the project as a tool to the project as a temporary organization. According to Andersen (2016), this perspective on project management focus on the close interaction and relationship between the permanent and temporary organization. The project assignment, which is performed by the temporary organization, is initiated by the permanent organization, and should be delivered when it suits the base organization. The main purpose of the project is therefore to create value in the base organization. Time and costs are not objectives in themselves, but rather framework conditions for the project.

These two different perspectives need different methodological approaches. The focus of the task perspective is on executing a project as a defined task. The goal is to complete the project as quickly as possible, with as low costs as possible, and with the prescribed quality. Phase-oriented models are relevant, because project work is seen as a sequential process. The focus of the organizational perspective is on the relationship between the project and its base organization. The goal is to fulfill the mission of the project and at the same time act as a basis for value creation in the receiving organization. Because planning and deliveries will happen throughout the project, phase-oriented models are not sufficient. A milestone plan made

when the project is initiated should be supplemented with more detailed plans as the project progresses (Andersen 2016).

*2.2.1.2   Knowledge management*

The uniqueness of the building design in each project, the complex processes and the uncertain nature of construction, mean that creativity, ingenuity and experience are needed to ensure successful project execution. The knowledge generated in a construction project is therefore an important asset, and the capture and reuse of this knowledge is critical for the successful execution of construction projects and for the competitiveness of each actor (Deshpande *et al.* 2014). With the rapid BIM adoption, the industry is undergoing transition to a new era of digital information. Still, the dominant form of knowledge on project execution still exists in the form of tacit knowledge (Nepal & Staub-French 2016).

Tacit (implicit) knowledge is the context-specific knowledge of individuals, acquired through experience that is difficult to formalize, record or articulate. In contrast, explicit knowledge is formal knowledge that can be packaged as information, codified and transmitted in a systematic and formal language (Tserng & Lin 2004). Because tacit knowledge covers the know-how of experienced staff, it is difficult to document and communicate. Explicit knowledge, on the other hand, is formal and systematic, and therefore easy to communicate and share, and can be stored through standard operating procedures, best practice guides, etc. (Carrillo & Chinowsky 2006). Capturing tacit knowledge and making it available as explicit knowledge opens up the possibility of reusing knowledge in other projects and preserving it as organizational property (Tserng & Lin 2004). Knowledge gained by a project team during a project is often not retained and used on future projects. A crucial step for counteracting this is the conversion of this tacit knowledge to explicit knowledge, since only explicit knowledge can be integrated into an organizational knowledge base. This conversion can be supported by knowledge management[13] (Lindner & Wald 2011). The construction industry is a knowledge-intensive and experience-based industry; knowledge management is therefore critical for process improvement. Systematic management of knowledge can encourage continuous improvement, sharing of tacit knowledge, the dissemination of best practice and a reduction in rework (Deshpande *et al.* 2014). To achieve this requires projects with what Lundin & Söderholm (1995) defines as repetitive tasks, which are tasks with specified goals, either through tacit knowledge or in codes, that will be repeated in the future. This is in contrast to unique tasks, which are tasks with abstract goals, that will not occur again.

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[13] Knowledge management can be defined as "the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage" (Carrillo & Chinowsky 2006: 2).

When implementing knowledge management, there can be several barriers, such as lack of standard processes, a weak organizational culture, insufficient funding, employee resistance and poor IT infrastructure (Yang *et al.* 2013). Implementation requires the establishment of means to motivate and facilitate individuals to develop, enhance, and use their knowledge in order to achieve organizational goals. Knowledge management systems can be implemented to facilitate the capture, access, and reuse of information and knowledge (Carrillo & Chinowsky 2006). Effective knowledge management systems have the ability to communicate and preserve knowledge across all stages of a construction project (Deshpande *et al.* 2014). The dominant type of knowledge management system that has been used in practice, is what Newell (2015) calls repository system, which is based on facilitating the sharing of explicit knowledge. To succeed, the repository must contain knowledge useful for employees looking for answers and solutions in execution of projects. The repository must not only contain useful knowledge, but the knowledge must be intuitive and easy to find. Development of knowledge management systems requires the investment of considerable financial and human resources (Yang *et al.* 2013; Lindner & Wald 2011).

There have been several examples of knowledge management systems developed for the construction industry, but only a few of these exploit the use of BIM as an efficient tool for visualizing construction progress and management. A BIM-based knowledge management system was developed by Lin (2014), enabling engineers to share and reuse their knowledge and experience during construction. Knowledge information were stored using BIM, through attributes in modeling objects. Deshpande *et al.* (2014) created a BIM-based knowledge management system, where important knowledge from lessons learned during engineering and construction were stored using BIM, through attributes in the modeling objects. The knowledge generated could then be published and used in other BIM projects. These and other similar systems are platforms for knowledge sharing in construction projects. They are solutions to share best practice using BIM. Despite this, none of these have adapted the knowledge and transformed that into common execution methods for construction projects.

### 2.2.2 The PEM used in the main themes

The PEM, which is referred to and used in the main themes in this thesis, is based on the Knowledge Areas in the PMBOK, especially the Project Integration Management Knowledge Area, with a focus on actions that are crucial for a controlled project execution (Kvaerner 2012d). Project Integration Management in PMBOK is about integrative actions crucial for controlled (managed) project execution. Similarly, BIM has positive impact on all Knowledge Areas in PMBOK (Bryde *et al.* 2013). A Knowledge Area directly related to BIM is Project Communications Management, which is about processes required to ensure handling of project information.

Because the PEM, used for managing and executing projects, is based on PMBOK, it thereby aligns with the principles of the task perspective (Andersen 2016). According to Bryde *et al.*

(2013), the Knowledge Areas in PMBOK extend beyond the focus of cost, time and quality, by reflecting the importance of success criteria related to such as the organization, stakeholder and management of information. PMBOK also emphasize the importance of project governance, which is "the alignment of project objectives with the strategy of the larger organization by the project sponsor and project team" (PMI 2013: 553). Project governance provides a method for controlling a project through documented best practices. Project governance enables organizations to manage projects, maximize the value of project outcomes and align projects with business strategy. This does not only correspond with the principles of the PEM, but also with the same principles as the organizational perspective (Andersen 2016). Despite that the PEM manly aligns with the principles of the task perspective, it also supports principles of the organizational perspective.

The PEM has been developed as an interactive system and presented as a three-level pyramid, to clearly define the methodology, simplify navigation and ensure consistency. The PEM has a strategic level on top, followed by a control level and an execution level (see Figure 5 below). The strategic level describes the life cycle of a project, split into phases with requirements for each phase. All phases are divided into multidiscipline stages, and the control level describes the stages to each of the phases, where each stage is ending up in a milestone. This is similar to the principles of a stage-gate process, where proper documentation must be provided at each gate or decision point, to determine if a project will go ahead to the subsequent phase (Cooper 1990). The purpose of a stage gate is to make sure the formal decision-making is successful (Klakegg 2017). A stage-gate process is usually the starting point when companies first acknowledge the need for developing standardized processes for project management. Successful use of a stage-gate process can provide structure, standardization and allow for structured decision-making (Kerzner & Kerzner 2017). Objectives and focus areas for each stage and milestone requirements are also defined at the control level. The strategic and control level are more general and should be used in all projects. What differentiates the PEM compared to other knowledge management systems and stage-gate models is the execution level. The execution level describes all work processes and activities to management and execution disciplines. This level is much more comprehensive than the first two, and the extent of its use will depend on the type, size and complexity of the project (Kvaerner 2012c).
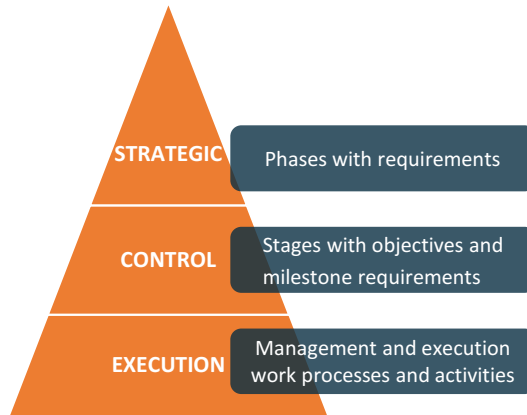
*Figure 5: The three levels of the PEM. Adapted from Kvaerner (2012c)*

The PEM, which describes how a project is managed and executed, can be differentiated from a project model, a project delivery model and an execution model. A project model can be defined as a standard classification of project phases, with decision points corresponding to milestones, and documentation requirements (Samset & Volden 2013). The phases are often related to tasks, ownership or responsibilities. Several public and private institutions and companies in Norway have developed their own project models (Haanæs *et al.* 2010). A project model can therefore be related to the top level of the PEM (strategic and control level). According to Klakegg (2017), a project model can consist of three key elements. The first is the project life cycle, which defines common project phases and stages. The second is stage gates, to fulfill a formal decision-making. The last is roles, with responsibilities and reporting lines. The last key element extends the definition of a project model, also including social interactions. While a project model can be seen as more generic and related to an institution or company, an execution model can be seen as more project specific (Meland 2017). An execution model can be perceived as both a type of project contract, such as design-build or design-bid-build, in addition to a contracting strategy, organizational culture and integration, and type of compensation for a project (Meland 2000). Similarly, project models can be transformed into specific project delivery models or project delivery methods[14] (PDM) for a project. A PDM can consist of five elements. The first is the organization model, with focus on decision making processes. The second is the form of specification for the project. The third is the structure, where project scope is defined through work packages and contract scope. The fourth is the procurement route, with focus on procurement procedures, contractual arrangements and compensation formats. The fifth is the format of the agreement, with contract format, conflict resolution procedures, risk sharing policies and compensation formats (Klakegg 2017). According to Økland *et al.* (2018), there is an ongoing debate in the

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[14] A project delivery method (PDM) can be defined as a system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a goods or service" (Miller *et al.* 2000: 2)

project management community of whether a project delivery model to an organization should be fixed or adapted to each project in the project portfolio. To summarize, an execution model and a PDM can be described as the framework conditions for a project, while a project model can be related to the top two levels of the PEM.

In the control level of the PEM, the outputs at the end of each stage are defined through milestones, and must be verified through stage gate reviews, in order to continue as input to the next stage. A milestone or stage gate is similar to what Schade *et al.* (2011) identify as a quality gate, where design maturity is coordinated and evaluated. This conversion from output to input can be related to the project management process, where the result or output of a process becomes the input of the subsequent process (PMI 2013). Similarly, executing projects more efficiently is about process management, and the efficiency of the conversion from input to output within budget and on schedule. Efficiency is achieved by "doing things right" (Crawford & Bryce 2003).

The relevance and potential applicability of the findings to the construction industry is increased if detail engineering is based on the same key objectives in both industries. In order to ascertain that there is correspondence between the objectives in each industry, I have used the stages of detail engineering in the PEM, as defined by Kvaerner and Aker Solutions (AkerSolutions 2014b), as a benchmark, and compared to stages in standards and industry norm initiatives in the construction industry, through the "life-cycle stages" of ISO 29481-1 (ISO 2010) and RIBA Plan of Work (RIBA 2013) (see Figure 6 below).
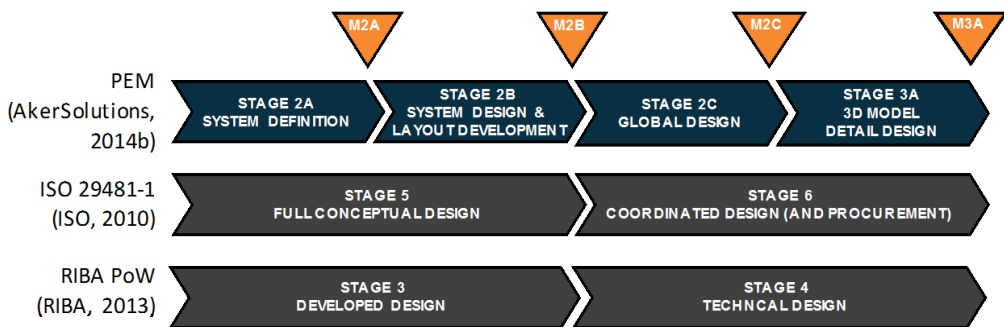


*Figure 6: Stages of detail engineering in the PEM, compared to the construction industry*

Detail engineering, as defined in the PEM, begins in stage 2A ("System definition"), with corresponding milestone M2A, where the concept design is confirmed and optimized. In stage 2B ("System design & layout development"), with milestone M2B, the main layout and structures are confirmed, and the detailed design premises are completed. These first two stages correspond to the "Full conceptual design" stage outlined in ISO 29481-1 and the "Developed design" stage outlined in the RIBA Plan of Work, where the concept design is developed, and the discipline designs are progressed until spatial coordination has been completed. When milestone M2C ("Global design complete") is reached, the designs are clash

free and complete, except for final detailing. In the final stage, 3A ("3D model detail design"), with milestone M3A, all disciplines have completed their designs, to a level ready for fabrication. These last two stages correspond to the "Coordinated design (and procurement)" stage in ISO 29481-1 and the "Technical design" stage in the RIBA Plan of Work, where the discipline designs are further refined to provide technical definition of the project. To summarize, the first two and last two stages of detail engineering in the PEM have similar key objectives to each of the corresponding two stages in ISO 29481-1 and the RIBA Plan of Work, which increases the relevance of the findings towards the construction industry.

A set of management and execution key deliverables[15] are also defined at the control level. The grade of completeness for a key deliverable at various stages in the project execution is described through quality levels[16] that are achieved at the major milestones (stage gates) (AkerSolutions 2009). This is illustrated in Figure 7 below, where the "3D Model" (building information model) key deliverable will achieve quality level 1 (QL1) at the M2A milestone, QL2 at the M2B milestone, QL3 at the M2C milestone, and QL4 at the M3A milestone (AkerSolutions 2014b).
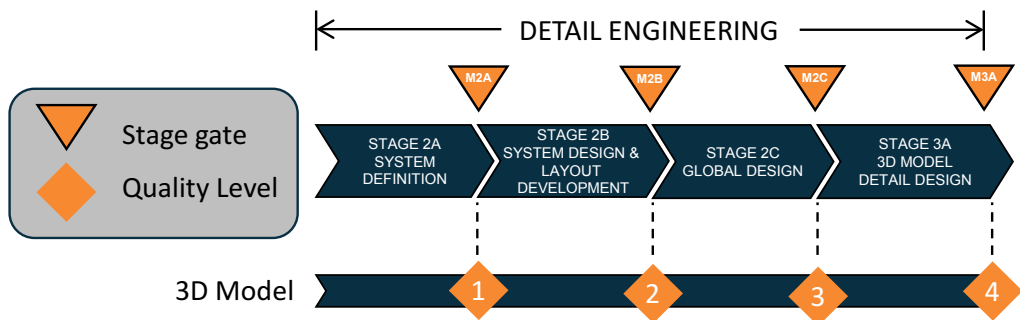


Figure 7: 3D Model key deliverable in the PEM - related to quality levels and milestones (AkerSolutions 2014a)

The execution level describes all work processes and activities related to the management and execution disciplines. The quality level description for the "3D Model" (building information model) key deliverable consists of several groups of control objects[17] for each discipline (Kvaerner 2012c). Unlike a modeling object in a building information model, a control object consists of several modeling objects of the same type, or modeling objects that are grouped together with related types of modeling objects. A truss is an example of a control object,

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[15] A key deliverable is a measurable deliverable with a defined set of information, which is multidisciplinary and critical to project execution, and released at different times during project execution (AkerSolutions 2009).

[16] A quality level is a defined grade of completeness for a deliverable. Each quality level is achieved at a certain milestone (AkerSolutions 2009).

[17] Unlike a modeling object in a building information model, a control object consists of several modeling objects of the same type, or modeling objects that are grouped together with other types of modeling objects. The grade of completeness for a control object is described by status descriptions (AkerSolutions 2009).

where the truss itself consists of several modeling objects, such as beams, columns, stay cables etc. The idea is to have a higher abstraction level more related to actual deliverables, and thereby reduce the number of objects and object types to coordinate. The degree of completion of each control object at each quality level is defined through status requirements. Put another way, quality levels describe maturity requirements for control objects in a building information model, from creation to completion, using different statuses (see Figure 8 below). The illustration shows an extract of a list of control objects for the structural discipline, with an extract from the "main structure" control object group, consisting of control objects and the different statuses these control objects have at each quality level. The quality levels coincide with the milestones at each stage of detail engineering. The disciplines have checklists that define requirements that must be fulfilled to achieve each status for the control objects.

| QUALITY LEVEL DESRCIPTIONS | | | | | | |
|---|---|---|---|---|---|---|
| Key deliverable: | | | STAGE 2A | STAGE 2B | STAGE 2C | STAGE 3A |
| **3D MODEL** | | | QL1 (M2A) | QL2 (M2B) | QL3 (M2C) | QL4 (M3A) |
| CTR No.: | STRUCTURAL Group of Control Object (GCO) | Check List | | | | |
| 0082 | Main Structure (MS): | | | | | |
| 0082 | Trusses | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Main support nodes | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Web framings | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Shells | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Bulkheads | 3D Model Structural | S1; "Preliminary". | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". |
| 0085 | Secondary Structure (SS): | | | | | |
| 0086 | Outfitting Structures (OS): | | | | | |
| 0087 | Small Item Structures (SIS): | | | | | |
| 0088 | Temporary Structures (TS): | | | | | |

*Figure 8: Control objects in the PEM with statuses for each quality level (AkerSolutions 2013b)*

A status is a defined grade of completeness for a control object. There are four main statuses of control objects in building information models in detail engineering (see Figure 9 below). These apply to all control objects. The first is S1 "Preliminary", where the control object still has a preliminary shape and location. The next is S2 "Released for verification/IDC", where the shape and location is set for interdisciplinary design control (IDC). In S3 "Frozen interface", the location of the control object and interface towards other disciplines are frozen. Critical actions from the IDC should be implemented and the building information models should be clash free. The last is S4 "Detail Design Completed", where the final detailing of the control

objects is completed and deliverables are ready to be issued for construction (Kvaerner 2013a).

| ENGINEERING STATUS DESCRIPTIONS | | | | |
|---|---|---|---|---|
| **GENERAL DISCIPLINE** | **"Preliminary"** <br><br> **S1** | **"Released for verification/IDC"** <br><br> **S2** | **"Frozen Interface"** <br><br> **S3** | **"Detail Design Completed"** <br><br> **S4** |
| 3D model control object | Control object modelled with simplified shape based on preliminary design from previous stage and estimated information. | Detailed shape with "not to exceed" outer dimensions and location approved by own discipline. | Control object completed with final shape and location. Verification/IDC comments implemented. Interfaces towards other control objects and other disciplines frozen. | Detail design of control object completed and approved for construction. Detailing shall not affect interfaces to other disciplines and control objects. |

*Figure 9: Status definitions for control objects in detail engineering (AkerSolutions 2013a)*

Another term that is used in the construction industry is level of detail or level of development (LOD). The LOD framework is an industry-developed standard to describe the state of development of modeling objects within a building information model. The LOD levels address the amount of detail on each modeling object and usability in other disciplines (Ramaji & Memari 2016), while status definitions expand this to define the quality and maturity of a building information model and the corresponding work sequences (AkerSolutions 2014b).

# 3   Research design

The research design has been structured according to research approach, research method, type of research, research strategy, data collection method and data analysis method (see Figure 10 below).
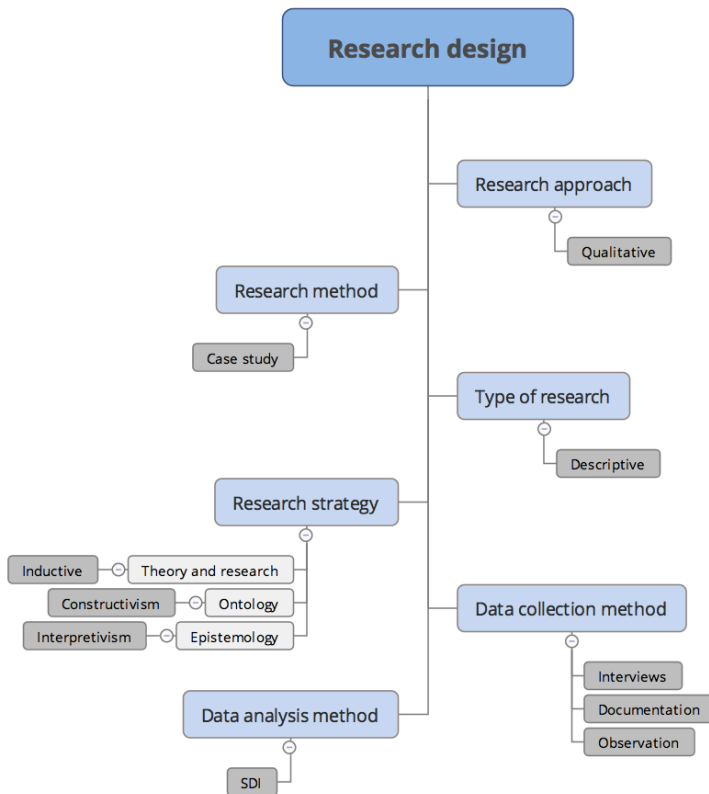


*Figure 10: Research design, adapted from Fellows & Liu (2009); Bryman (2012)*

The research approach is qualitative, where the methods used can describe and interpret a phenomenon in a given context so that it leads to a better understanding of the phenomenon. This is in contrast to quantitative research, where data is generated and forms the basis for numerical analysis. The assumption is that the phenomenon to be studied can be defined and delineated relatively unambiguously (Justesen & Mik-Meyer 2012). All empirical data are from ongoing and recently completed projects in the oil and gas industry, which have been collected and analyzed through qualitative research. Qualitative research can be driven by both empirical data and theory, and often a mix of both. Understanding of and proximity to the phenomenon that is being researched, with an open interaction between researcher and informants, is emphasized (Tjora 2012).

The research method is case study, where the focus is on the study of single cases or a small number of cases. Case studies focuses on the case in its context, typically using multiple methods of data collection (Robson 2011). Case study research is used to describe the phenomena in certain cases, through ongoing projects. There can be three types of case studies – exploratory, descriptive and explanatory (Yin 2009). The type of case study is mainly descriptive, because it documents the phenomenon of interest (Fellows & Liu 2009). The research is about gaining more in-depth knowledge related to the use of a PEM and utilization of BIM in projects in the oil and gas industry. It is also partly explanatory, in that a phenomenon is investigated through a hypothesis that is set up and then tested through research. This is in contrast to exploratory, which is theory-driven and aims at generating hypotheses (Fellows & Liu 2009). The assumption I made is that experiences on the use of a PEM and utilization of BIM in oil and gas projects, can support improvements in execution of construction projects.

Research strategy is about the connection between theory and research, ontology and epistemology (Bryman 2012). The relationship between theory and research refers to whether theory guides research or whether theory is an outcome of research. The first, where theory guides research, is a deductive approach, where the focus is on the testing of theories through observation and findings. The second, where theory is an outcome of research, is an inductive approach, where the focus is on generation of theories based on observation and findings. It is both exploratory and empirically driven, where some general context is assumed or developed based on observation of individual cases (Tjora 2012). When a theoretical reflection has been carried out on a data set, the researcher can collect more data in order to establish the conditions in which a theory will hold (Bryman 2012). My research has followed an inductive approach. Data has been collected from case projects and analyzed, with a view to developing findings that can be discussed based on relevant research.

Ontology is about how the part of reality constituting the object of study is viewed (Justesen & Mik-Meyer 2012). There are two main ontological positions. The first is objectivism, whereby social reality is viewed as an external, objective reality, and social phenomena and their meanings exist independently of social actors. The second is constructivism, where social phenomena and their meanings are continually developed by social actors. The idea is that the researcher's own definition of the social world is a construction, and they present a specific version of social reality, rather than one that can be regarded as definitive (Bryman 2012). My research has followed a constructivist position, where the case projects studied have been highly dependent on the resources involved in the projects. The findings have been based on analysis of data collected from the case projects.

While ontology is about the part of reality that is the object of the study, epistemology is about the ability to acquire knowledge of this area (Justesen & Mik-Meyer 2012). There are two main epistemological positions. The first is positivism, which supports the use of the methods of

natural sciences in the study of the social world. The second is interpretivism, which emphasizes the way individuals interpret their social world. It requires a strategy that respects the differences between people and the objects of the natural sciences, and therefore requires that the researcher is dedicated to the subjective meaning of social action (Bryman 2012). My research has followed an interpretivist direction, where my interpretation of the case projects I have studied, and their contexts, has determined the results of the research. I have followed case projects as a researcher, without any formal role in these projects. The findings have been based on my interpretation of the data collected from the actors involved.

Data collection is about obtaining an appropriate set of data to permit the research to realize the objectives, by addressing the research questions, as thoroughly as possible (Fellows & Liu 2009). The data collection methods used are interviews, document studies, and observations. Data analysis is about the management, analysis and interpretation of the collected data (Bryman 2012). The data analysis method used is the stepwise-deductive-inductive method (SDI) (Tjora 2012). The principle of this method is to work in a series of steps from data to concepts or theories (inductive) and then go back to the data to empirically verify those concepts or theories (deductive). This has been supported using CAQDAS.[18]

The description of case study as a research method (3.1) is followed by an account of how the cases were selected, and a short presentation of each case (3.2). This is succeeded by how the data collection methods are used, which includes a description of the interview process (from recruitment through to transcription), as well as the document studies and observations completed (3.3). The data analysis method, SDI, and the use of CAQDAS, are then presented (3.4). Finally, the quality of this case study research project, with regard to validity, reliability, generalization and ethics is discussed (3.5).

## 3.1   Case study research

Case study is chosen as the research method. It is an approach to research involving an empirical investigation of a contemporary phenomenon within its real-life context (Yin 2009). Because it is empirical, it relies on the collection of evidence, through the study of specific cases of interest. In this thesis, the cases are offshore projects in the oil and gas industry. Case studies use multiple sources of data, collected using a range of methods. In this thesis, interviews, document studies and observations are used. The details of the design typically emerge during data collection, and the subsequent analysis (Robson 2011; Yin 2009). The choice of a case study approach is based on a framework defined by Yin (2009). In this framework, three conditions determine the choice of methods. These are the form of the research question, the extent of control a researcher has over actual behavioral events, and

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[18] CAQDAS (Computer-Assisted Qualitative Data Analysis Software) refers to "any software that is specifically designed to analyze qualitative text" (Sinkovics & Alfoldi 2012: 819).

the degree of focus on contemporary events. As stated in Paper 1, all three conditions for using case study as a research method are fulfilled: the form of the research questions are "How"; I have had no control over behavioral events in the projects I have studied as cases; and my focus is on contemporary events through ongoing projects.

## 3.2    Selection of cases

At the start of my doctoral period, Kvaerner, a Norwegian EPC contractor in the oil and gas industry, agreed to make certain projects and informants available for my research. The agreement was coordinated with the help of my supervisor at Multiconsult, who had previously worked at Kvaerner. I had the opportunity to access three ongoing projects and informants related to these. All three projects were selected by Kvaerner. These were not only the first oil and gas projects accessible to me, they were subsequently selected as cases for my thesis, because of their use of a PEM and utilization of BIM in project execution. The case projects were initially the Nyhamna onshore facilities, and the topsides of the Eldfisk and Edvard Grieg offshore production platforms. The topsides hold the facilities to process oil and gas from the reservoir in the seabed below and have been designed and built for installation on steel jackets. All three projects were executed with Kvaerner as EPC contractor, and with Aker Solutions as engineering and procurement subcontractor. Both companies deliver oil and gas projects in Norway and internationally in other major oil and gas regions. Kvaerner and Aker Solutions completed a demerger in 2011 and are now two separate companies, but still with the same owner. The reason for choosing Kvaerner, and subsequently Aker Solutions, was their development and use of the PEM, and how that was linked to BIM, the positive experiences Multiconsult has had in collaborating on projects as engineering subcontractor, and their leading national and global positions as providers to the oil and gas industry.

Because of a lack of access to relevant informants at the Nyhamna project, this case was soon abandoned. A new case, the topside of one of four Johan Sverdrup platforms, was introduced by Kvaerner in 2015 and added as a case in 2016. The project is executed as an EPC contract in a joint venture between Kvaerner as EPC contractor and KBR as engineering and procurement contractor. With increasing project size and complexity, a joint venture is widely used in the oil and gas industry to share risk and increase the capability between companies (Rui *et al.* 2017). This created the opportunity for a case with a different engineering contractor than in the other two cases, required a different project organization to that which Kvaerner had with Aker Solutions. This also made it possible to explore the dynamics between the EPC contractor and engineering and procurement contractors in project execution. Flyvbjerg (2006) defines different strategies for case selection. The strategy used in this thesis is "information-oriented selection", where the focus is on maximizing the utility of information from a few cases. Even though the Johan Sverdrup case is different from the other two in terms of the project organization, the cases were, as far as possible, selected to obtain similar results. The case projects were identified by Kvaerner and were selected based on the

information they could contribute on the use of a PEM and utilization of BIM. The three cases are all topsides of offshore platforms, executed as EPC contracts. Because this study consists of three cases, it can be characterized as a "multiple-case design". With two cases or more, the evidence is considered more compelling and more robust than a "single-case design" (Yin 2009).

### 3.2.1 Eldfisk

Kvaerner was in March 2011 awarded a contract by ConocoPhilips to perform EPC of the topside of the Eldfisk 2/7 S integrated production platform,[19] at the Eldfisk field in the Greater Ekofisk Area in the southern part of the North Sea (see Figure 11 below). The estimated contract value was 5.5 billion NOK. The topside, with a total weight of 15,500 tons, consists of a combined living quarters and utility module and a combined process and wellhead module. It was completed in April 2014, as planned, on time and to the specified quality.[20] The contract was awarded to Kvaerner, as EPC contractor, prior to the demerger of Aker Solutions. Aker Solutions continued as an engineering and procurement subcontractor after the demerger. The project was executed with fabrication deliveries subcontracted to partners in Poland and Finland, and fabrication and assembly at the Kvaerner yard at Stord, Norway. The living quarters including utility has an area of 5,000 m², with a capacity of 154 single cabins, recreation areas, changing rooms and operation facilities. Apply Leirvik assisted in the outfitting and completion. [21]

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[19] See https://www.kvaerner.com/toolsmenu/Media/Press-releases/2013/Kvarner-ASA--Kvaerner-to-perform-Eldfisk-27-S-offshore-hook-up-and-commissioning-assistance/ (Accessed 19.05.2017)
[20] See https://www.kvaerner.com/toolsmenu/Media/Press-releases/2014/Kvarner-ASA-Kvaerner-delivers-Eldfisk-27-S-topside/ (Accessed 19.05.2017)
[21] See http://www.applyleirvik.no/news/p/apply-takes-an-extended-role-in-kvaerner-stord-s-eldfisk-2-7-s-project?ctl=Details&neID=5692&mid=3713 (Accessed 07.09.2017)

*Figure 11: Eldfisk[22]*

### 3.2.2   Edvard Grieg

Kvaerner was in May 2012 awarded a contract by Lundin to perform EPC of the topside of the Edvard Grieg platform[23] in the North Sea (see Figure 12 below). The estimated contract value was 8 billion NOK. The topside, with a total weight of 21,000 tons, consists of a combined living quarters and utility module, a process module and a flare tower. It was completed in April 2015, as planned, on time and to the specified quality.[24] The contract was awarded to Kvaerner as EPC contractor, with engineering and procurement on a subcontract, performed by Aker Solutions in Oslo and Mumbai.

Fabrication and assembly of the process module was conducted at the Aker Solutions yard in Egersund, Norway. The engineering and construction of the living quarters, which is a seven-floor offshore hotel with an area of 2,600 m² and a capacity of 100 single cabins plus operation facilities, was subcontracted to Apply Leirvik.[25] The rest of the topside was fabricated and assembled at the Kvaerner yard at Stord, Norway.

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[22] Illustration of Eldfisk. See https://www.kvaerner.com/Products/Topsides/Eldfisk-2/ (Accessed 27.10.2017)
[23]   See   https://www.kvaerner.com/toolsmenu/Media/Press-releases/2012/Kvarner-ASA-Kvaerner-awarded-Edvard-Grieg-topside-EPC-contract-/ (Accessed 26.05.2017)
[24] See https://www.kvaerner.com/toolsmenu/Media/Press-releases/2015/Kvarner-ASA-Edvard-Grieg-topside-completed-on-time/ (Accessed 26.05.2017)
[25]   See   http://www.applyleirvik.no/news/p/edvard-grieg-living-quarter-to-apply-leirvik?ctl=Details&neID=2929&mid=3713 (Accessed 07.09.2017)

*Figure 12: Edvard Grieg[26]*

### 3.2.3   Johan Sverdrup

Kvaerner, in a joint venture with KBR, was in June 2015 awarded a contract by Statoil for the complete delivery of the topside of one of four platforms in the Johan Sverdrup oil and gas field[27] in the North Sea (see Figure 13 below). The estimated contract value was 6.7 billion NOK. The topside, with a total weight of 19,000 tons, consists of the utility and living quarters. Detail engineering started in 2015.[28]

The joint venture was established in August 2014 to bid on contracts for the offshore platform topsides in the Johan Sverdrup field development.[29] Detail engineering is performed at KBR's office in Leatherhead, England. The engineering and construction of the accommodation module for the living quarters platform, which is a seven-floor offshore hotel with an area of 14,500 m$^2$ and a capacity of 560 beds, recreation areas, changing rooms, helicopter deck and hangar, plus operation facilities, has been subcontracted to Apply Leirvik[30] at Stord, Norway. The other modules for the utility and living quarters platform will be constructed at yards in

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[26] Illustration of Edvard Grieg. See https://www.kvaerner.com/Documents/News/Edvard%20Grieg%20fact%20 sheet.pdf. (Accessed 27.10.2017)
[27] See https://www.kvaerner.com/toolsmenu/Media/Press-releases/2015/Kvarner-ASA-Kvaerner-KBR-JV-wins-Johan-Sverdrup-platform-contract-/ (Accessed 26.05.2017)
[28] See http://www.kvaerner.no/en/toolsmenu/Media/Press-releases/2016/Kvarner-ASA-Construction-start-with-increased-Norwegian-content-for-Johan-Sverdrup-platform/ (Accessed 07.09.2017)
[29] See https://www.kvaerner.com/toolsmenu/Media/Press-releases/2014/Kvarner-ASA-Kvaerner-and-KBR-join-forces-for-Johan-Sverdrup-contracts-/ (Accessed 26.05.2017)
[30] See http://www.applyleirvik.no/news/p/largest-contract-ever-to-apply-lq-helidecks-apply-to-build-johan-sverdrup-accomodation-module-?ctl=Details&neID=6263&mid=3713 (Accessed 07.09.2017)

Poland and Sweden. The Kvaerner yard at Stord will assemble all parts for the utility and living quarters platform before the platform is installed in the field in 2019.[31]



*Figure 13: Johan Sverdrup[32]*

## 3.3    Data collection

The primary sources of data are interviews supported by document studies. I have conducted interviews with informants in key positions in the case projects. This is considered a two-way communication, which allows feedback and the gathering of additional data, and can be regarded as non-linear data collection (Fellows & Liu 2009). I have received relevant company and project documentation as a supplement to the interviews. The secondary source of data is observations. Both document studies and observations can be categorized as one-way communication, because there is no interaction, and regarded as linear data collection (Fellows & Liu 2009).

Initially, all data was collected through Kvaerner. In 2016, as the Johan Sverdrup project was added as a case, an opportunity opened up to collect data through KBR as well. By signing a non-disclosure agreement (NDA) with Kvaerner, I was able to gain permission from KBR to interview informants that were part of the Johan Sverdrup project. Just prior to this, also in 2016, a meeting with representatives from Aker Solutions was initiated, through one of the contacts of my supervisor at Multiconsult. Aker Solutions gave me permission, after signing

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[31]    See    https://www.statoil.com/en/news/construction-start-johan-sverdrup-platform.html    (Accessed 07.09.2017)
[32] Illustration of Johan Sverdrup. See https://www.kvaerner.com/Global/PRAttachments/691552.pdf (Accessed 27.10.2017)

an NDA, to interview informants related to the Eldfisk and Edvard Grieg project, in addition to the Johan Sverdrup project, on which they have the system responsibility for the overall field development for all four platforms. From then on, I was able to collect data through interviews, document studies and observations, with Aker Solutions and KBR, in addition to Kvaerner, related to the three cases Eldfisk, Edvard Grieg and Johan Sverdrup.

### 3.3.1   Interviews

Interviews have been conducted in a semi-structured format with the use of interview guides (Bryman 2012). A semi-structured interview is closely related to a "focused interview" (Merton *et al.* 1956), where the interviewee is interviewed for a short period of time, by following a pre-defined set of questions, based on the case study. The interviews can still be open-ended and take the form of a conversation (Yin 2009). The interview guides comprised questions related to the topics to be covered in each interview. The questions were often sent to the interviewee in advance, so that they could have time to prepare. An example of an interview guide used in interviews with Kvaerner, Aker Solutions and KBR in June 2016 is included in Appendix A. The questions were not always asked in the exact order outlined in the interview guide, and the interview guides were often modified, based on the flow of each interview, with additional unplanned questions asked to follow up on what the interviewee had said. The goal was to get the interviewees to reflect on their own experiences and opinions related to the themes of the research. The use of open-ended questions (Tjora 2012) meant the interviewees had the opportunity to answer in depth when needed. Being open to digressions from the interviewees has in several instances led to aspects that were not anticipated, but that have been seen as important for the interviewees and thereby relevant for the research. To ensure that all relevant questions in the interview guides were answered, any unanswered questions were followed up in subsequent interviews.

Data was collected through 25 semi-structured interviews, conducted between February 2013 and June 2016. This includes 15 interviews with informants from Kvaerner, five with informants from Aker Solutions and five with informants from KBR. All interviews were conducted in Norwegian, except for the interviews with the informants from KBR, which were conducted in English. The average length of the interviews was 1 hour 31 minutes. The interviews were conducted with up to three informants in key positions (see Table 1 below). About one third of all interviews were conducted with two or more interviewees. These group interviews encourage interaction between interviewees, and allow the establishment of a consensus view (Fellows & Liu 2009). Several of the interviews have been followed up over a period of time, to be able to gather necessary information and to capture potential changes and patterns over time.

| Interview date | Interview duration | Inteview source | Interviewee 1 role | Interviewee 2 role | Interviewee 3 role |
|---|---|---|---|---|---|
| 130215 | 02:22 | Kværner | Information Manager | Information Manager | |
| 130311 | 01:55 | Kværner | Information Manager | Project Manager | |
| 130419 | 01:10 | Kværner | Information Manager | | |
| 130808 | 02:04 | Kværner | Information Manager | | |
| 131126 | 02:29 | Kværner | Information Manager | Discipline Lead | |
| 131126 | 01:20 | Kværner | Information Manager | PEM Manager | |
| 140314 | 02:00 | Kværner | Project Manager | | |
| 141218 | 03:12 | Kværner | Project Manager | | |
| 150226 | 01:12 | Kværner | Project Manager | | |
| 150511 | 01:31 | Kværner | Project Manager | | |
| 151016 | 01:25 | Kværner | Project Manager | | |
| 160121 | 01:21 | Kværner | Project Manager | | |
| 160122 | 01:20 | Aker Solutions | System Eng. Manager | | |
| 160428 | 01:26 | Aker Solutions | Engineering Manager | Engineering Manager | |
| 160617 | 01:37 | Aker Solutions | Engineering Manager | Engineering Manager | |
| 160620 | 01:25 | KBR | Engineering Manager | | |
| 160620 | 01:27 | KBR | Information Manager | CAD Manager | Data Manager |
| 160620 | 00:48 | Kværner | Integration Manager | | |
| 160621 | 00:47 | KBR | Deputy Project Director | | |
| 160621 | 00:39 | KBR | Procurement Planning | | |
| 160621 | 00:30 | KBR | Engineering Manager | | |
| 160621 | 00:43 | Kværner | Construction Method Lead | | |
| 160621 | 01:01 | Kværner | Integration Manager | | |
| 160624 | 02:27 | Aker Solutions | PEM Manager | | |
| 160627 | 01:54 | Aker Solutions | PEM Manager | Planning Manager | |
| **25** | **38:05** | **TOTAL** | | | |
| | **01:31** | **AVERAGE** | | | |

*Table 1: Overview of interviews conducted as part of data collection*

At the start of my doctoral period, the main informant was appointed by Kvaerner, based on my focus on the use of a PEM and BIM in oil and gas projects. As Information Manager, responsible for all aspects of information handling in projects, the main informant had in-depth knowledge on the use of the PEM and BIM in projects, and had also assisted on information management on all three case projects. He was the main informant in the first six interviews during the first year of my doctoral program. He recruited the Information Manger on the Eldfisk case project in the first group interview. The Project Manager, who had been supporting all three case projects, was recruited for the second group interview. During a field visit to the Kvaerner yard at Stord, two group interviews were also conducted, one with the main informant and the PEM Manager at Kvaerner and Edvard Grieg, and one with the main informant and the Structural Discipline Lead at Edvard Grieg. Because my initial main informant was due to retire, the Project Manager from the second interview took over as my second main informant for the following six interviews.

The NDA agreements with Kvaerner and Aker Solutions were signed at the time when Johan Sverdrup replaced Nyhamna as the third case project. By that time, my second main informant was also due to retire. A third main informant for Kvaerner was introduced. He was Integration

Manager on the K2JV (Kvaerner and KBR joint venture on the Johan Sverdrup project) engineering team. He also coordinated my field trip to KBR's office in Leatherhead, England, where the K2JV engineering team were co-located. During the field trip, a total of eight interviews were conducted, with informants from both KBR and Kvaerner. This included two interviews with the third main informant, one with the Deputy Project Director, two with the Engineering Manager, one with the Procurement Planning Lead, and a group interview with the Information Manager, CAD Manager and Data Manager. The main informant at Aker Solutions was Head of Project Management, and also supported their engineering team at Johan Sverdrup. He coordinated interviews with other relevant informants. A total of five interviews at Aker Solutions were completed, including one interview with a System Engineering Manager, two group interviews with the main informant and the Engineering Vice President, one interview with the PEM Manager and a group interview with the PEM Manager and Planning Manager.

The selection method used to recruit informants is similar to the "snowball method", whereby the researcher begins with a small selection of informants which gradually grows as they are directed by initial recruits toward new potential informants. The method is widely used in studies where it is difficult to recruit an adequate selection of informants before the study starts (Tjora 2012). This was the situation in my case study, where I was entirely dependent on the main informant initially appointed to me. This informant gave me access to the informants recruited subsequently, including the second and third main informants, until sufficient data from interviews had been collected.

The people who are targeted as informants often receive many requests. As their time are precious, they become less willing or unable to provide data. There were periods, especially in 2014 and 2015, where I had to follow up the second main informant at Kvaerner over several months to get appointments for new interviews. This contributed to delays in the overall progress, due to a shortage of data input for ongoing papers. According to Fellows & Liu (2009), confidentiality may be advisable as a means to obtaining fuller and more readily given responses. As data collected in case study research are in-depth, researchers are more likely to encounter commercially-sensitive issues. When the NDAs with Kvaerner and Aker Solutions were signed in 2016, this issue was eliminated, and I gained access to more informants from the case projects.

### 3.3.1.1 Transcription

Transcribing means transforming, switching from one form to another. When interviews are transcribed from oral to written form, they are structured so that they are better suited for analysis (Kvale 2009). According to Fellows & Liu (2009), recording interviews can be very helpful in the analysis, to ensure accuracy in responses. The interviews were transcribed in the same language as they were conducted. Relevant parts of the interviews transcribed in Norwegian were translated into English, when used in the research. With permission from the

interviewees, I used a digital voice recorder to record all of the interviews and transcribed the audio almost in detail and almost in full. Only parts of the interviews that were not in any way relevant to the existing or future research were omitted. By using a voice recorder, I could concentrate more on the interviewees and dynamics of the interviews. A copy was kept of all written documents, presentations, reports, illustrations and pictures that were developed or presented by the interviewees in the interviews.

### 3.3.2  Document studies

A document study involves the analysis of documents created for other use than research (Tjora 2012). The main purpose of the use of documents is as a supplement to empirical data collected through the interviews. The use of documents has not only been to get access to relevant data to be used as examples and illustrations, but also to corroborate the data collected through interviews and observation. This has been done to verify what has been mentioned in the interviews, and to acquire new or additional information necessary to a full understanding (Yin 2009). The documents can be divided into relevant company and project documents. The company documents studied consist of flow charts, procedures, user manuals, policy documents and presentations. The project documents consist of tender documents, presentations, governing documents, procedures, schedules, work instructions, process documents and reports. These are documents that have been extracted from the case projects by the informants.

### 3.3.3  Observations

Observations have been useful for understanding more about the cases studied, as a supplementary data collection method (Robson 2011), to complement or set in perspective data obtained through interviews and document studies. I have used direct observations (Yin 2009), carried out by me as a researcher, through field visits. The observations has been informal, which is less structured, and allows considerable freedom in what information is gathered, and how it is recorded (Robson 2011). Two instances of direct and informal observation merit mentioning in particular. The first was the field visit to the Kvaerner yard at Stord. The field visit was made in November 2013, when the Edvard Grieg topside was assembled at the yard. I conducted two group interviews. To complement these, I received a guided tour of the site. Through direct observation, I was able to get a better understanding of the fabrication and assembly process at the yard. This was documented with several photos. The second was the field visit to the K2JV engineering team at KBR's office in Leatherhead, England, in June 2016, where I conducted interviews. These were complemented with observation of the project facilities and co-location of the engineering team. Here, the aim of the direct observations was to capture the dynamics of the engineering team's work environment. All other interviews were held at Kvaerner's and Aker Solutions' headquarters on the outskirts of Oslo, where direct and informal observations were made to

better understand the work environment and to capture the dynamics between the interviewees in the group interviews.

## 3.4   Data analysis

### 3.4.1   SDI method

The data has been analyzed using the stepwise-deductive-inductive (SDI) method (Tjora 2012). The principle of this method is to work in a series of steps from data to concepts or theories (inductive) and then go back to the data to empirically verify those concepts or theories (deductive). The steps in the SDI method start with the upward – inductive – process, moving from the generation and processing of empirical data, through coding, categorization of the codes, development of concepts, discussion of the concepts and use of theory, towards theory development. The downward – deductive – feedback loops involve working backwards from theory, to concepts, through the main themes, to "code-structured" data, processed data, raw data and back to the chosen sample (see Figure 14 below).
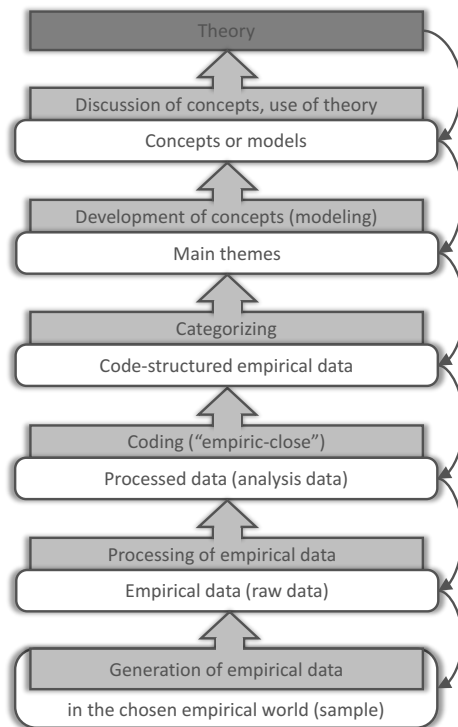


*Figure 14: SDI method, translated and adapted from Tjora (2012)*

Once the interview data had been transcribed, CAQDAS was used for the "empiric-close" coding, which reflects the contents of the transcript. The set of "empiric-close" codes can only be generated from the empirical data and not in advance. It can therefore not be based on

theory, hypotheses, research questions or planned themes. I used HyperRESEARCH,[33] which is a software for managing and documenting the research process more effectively. With the use of HyperRESEARCH, links were established between the set of codes and the instances in the empirical data these codes are connected to (see Figure 15 below). This creates "code-structured" empirical data.
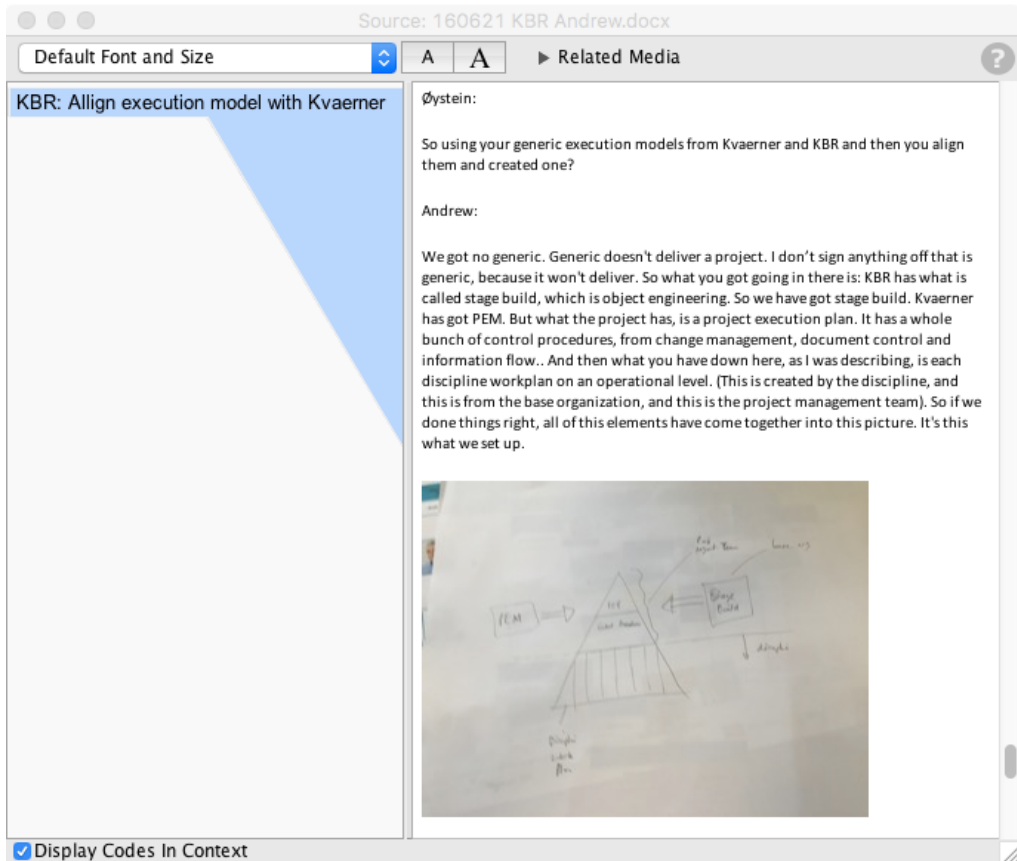


Figure 15: Screenshot from HyperRESEARCH showing "empiric-close" coding

This has been an iterative process. First, all (relevant) parts of the transcribed data from an interview were given codes based on the contents. Having set the codes in an interview, all similar codes where renamed to a common code. All codes in the interview where then compared to the "empiric close" codes in the database in CAQDAS, generated from the other interviews. New codes were added to the database. If any of the codes in the interview were similar to the "empiric close" codes in the database but formulated differently, these were renamed to avoid different code names for similar codes. All codes relevant for the research

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[33] See http://www.researchware.com/products/hyperresearch.html (Accessed 11.05.2017)

were sorted into larger groups of themes, called categories. The goal was to develop a few themes (categories) that extract the potential from the empirical data and address the research questions.

I developed a total of 210 codes and sorted 199 of these into 11 categories. The remaining codes were not relevant for the research and remained uncategorized. Each category comprised of codes describing similar topics that were grouped together. Of the 11 categories, seven were defined as primary categories, comprising 161 codes. The remaining four were considered secondary categories and reserved for potential future use. Of the seven primary categories, one was related to main theme 1, "Manage change in detail engineering using a change control system and BIM", three were related to main theme 2, "Report progress in design using BIM", and the last three were related to main theme 3, "Improve transition and collaboration between engineering and construction using a project execution model and BIM". Based on number of instances of the codes within each of these categories, Table 2 below shows the themes that emerged in each interview. Only five or more instances of each relevant code in each interview are included. Main theme 1 is identified in seven interviews, main theme 2 in 16 interviews and main theme 3 in 15 interviews.

| Key concepts | Interview date | Interview duration | Inteview source | Main theme 1 | Main theme 2 | Main theme 3 |
|---|---|---|---|---|---|---|
| BIM | 130215 | 02:22 | Kværner | x | x | |
| PEM | 130311 | 01:55 | Kværner | | x | x |
| PEM | 130419 | 01:10 | Kværner | | x | x |
| BIM | 130808 | 02:04 | Kværner | | x | |
| BIM | 131126 | 02:29 | Kværner | | x | |
| PEM | 131126 | 01:20 | Kværner | | x | x |
| PEM | 140314 | 02:00 | Kværner | x | x | x |
| PEM | 141218 | 03:12 | Kværner | x | x | x |
| PEM | 150226 | 01:12 | Kværner | x | | |
| BIM | 150511 | 01:31 | Kværner | | x | |
| PEM | 151016 | 01:25 | Kværner | | | x |
| PEM | 160121 | 01:21 | Kværner | x | | |
| PEM | 160122 | 01:20 | Aker Solutions | x | | |
| PEM | 160428 | 01:26 | Aker Solutions | x | | x |
| PEM | 160617 | 01:37 | Aker Solutions | | x | x |
| BIM | 160620 | 01:25 | KBR | | x | x |
| BIM | 160620 | 01:27 | KBR | | x | x |
| PEM | 160620 | 00:48 | Kværner | | | x |
| PEM | 160621 | 00:47 | KBR | | | x |
| BIM | 160621 | 00:39 | KBR | | x | |
| BIM | 160621 | 00:30 | KBR | | | |
| PEM | 160621 | 00:43 | Kværner | | | x |
| PEM | 160621 | 01:01 | Kværner | | x | x |
| PEM | 160624 | 02:27 | Aker Solutions | | x | x |
| BIM | 160627 | 01:54 | Aker Solutions | | x | |

*Table 2: Overview of main themes covered in each interview*

Categories are used as a basis to develop concepts, and in turn typologies or models - which are more theoretically inspired and establish a more general understanding of the phenomenon. The concepts are here related to the main findings in the research, as reflected in the themes. The SDI method follows a linear approach, but the process is iterative. It might well be that after having defined categories or developed concepts (inductive), there is a need to go back to generate more empirical data to support or expand these (deductive), as illustrated by the upward and downward arrows in Figure 14 above. This was the case in my research, where Aker Solutions and KBR were added to expand the empirical data. Using CAQDAS helps to facilitate the move from a traditional, linear progress to a non-linear and iterative process (Sinkovics & Alfoldi 2012).

The inductive process in the SDI method is similar to a thematic coding approach (see Robson (2011) for a discussion), where all parts of the data are coded and labeled, and sorted into potential themes. The codes and themes are determined by analyzing the data, based on its relevance to the research questions. The themes serve as a basis for further analysis. A thematic coding approach is similar to what Strauss & Corbin (1990: 61) call "open coding", which is "the process of breaking down, examining, comparing, conceptualizing and categorizing data". It is also similar to that Halkier (2011) describes as "category zooming", which is a three-step process for generalizing from the qualitative data, beginning with coding and categorizing, then tracing systematic relationships between categories, and finally conceptualizing. Common among these three approaches is what Kvale (2009) calls "concept-driven" coding, where the codes have been developed in advance, through parts of the data or the existing literature. The main difference between these approaches and the inductive process in the SDI method is what Kvale (2009) calls "data-driven" coding, where no codes have been defined in advance, but are developed through the analysis of the data. This is reflected in the "empiric-close" coding step. This is similar to, and based on, a grounded theory approach (see Robson (2011) for a discussion), where the goal is to develop a theory "grounded" in the data, where the codes are developed based on the interaction with the data, through the interpretation of the meanings in the texts.

### 3.4.2   CAQDAS

Computer-assisted qualitative data analysis software (CAQDAS) is aimed at making the analysis of large volumes of data more manageable and transparent (Gibbs 2014; Yin 2009). The variant selected for the project is HyperRESEARCH. Using HyperRESEARCH, all word-processed data, including interview transcriptions, and extracts from relevant company documents, have been imported directly into a project file. Visual data, such as sketches drawn by interviewees, photographs, figures and tables, has also been linked to the relevant transcripts. As a result, the project file can be treated as a hub for the data collected from various sources over time (Sinkovics & Alfoldi 2012). The project file contains all stored data, except documents that are not directly related to the text, such as external reports,

presentations, spreadsheets and illustrations. The references are stored in EndNote,[34] a software designed for managing bibliographies and references. HyperRESEARCH has also served as a data analysis tool. It has been used actively in defining and developing codes and categories, and the relationships between these, as a basis for developing concepts. Using HyperRESEARCH has allowed a more complex and detailed coding than could have been accomplished with manual thematic coding. The report function, which offers a range of ways of displaying results, and the extended search function, have been particularly useful in this process.

## 3.5  Research quality

Three criteria are often used to indicate quality in qualitative research in general and more specifically in case study research. These are validity, reliability and generalization (Yin 2009; Bryman 2012; Kvale 2009; Robson 2011; Tjora 2012; Fellows & Liu 2009). In qualitative and case study research that involves interactions with informants, ethical concerns are also important with regard to the quality of research. It is therefore added as a fourth criterion in this discussion on quality. The four criteria are introduced and related to the research in turn below, to assess whether or not they have been fulfilled.

### 3.5.1  Validity

In general, validity is about whether the research findings actually shed light on the research questions, or if what is said to be measured is actually measured (Justesen & Mik-Meyer 2012). In other words, validity is about whether the answers we find in our research are in fact answers to the questions we set out to answer (Tjora 2012). Yin (2009: 40) has defined "construct validity" as "identifying correct operational measures for the concepts being studied". To fulfill this, multiple sources of evidence must be used, a chain of evidence must be established, and key informants should be invited to review the results from the case study. Opportunities for data triangulation, where information is collected from multiple sources, to challenge a single source, or to get a fuller picture of a phenomenon, is one of the potential strengths of data collection in case study research.

Data has been collected through interviews and access to relevant company and project documents, supplemented with direct observations through field visits. To establish a chain of evidence is to allow an external observer to follow the derivation of any evidence from initial research questions to final case study conclusions. Having a single and accessible hub for systematically collected and analyzed data, through the use of CAQDAS, can help to establish a chain of evidence (Yin 2009). This is supported by Kvale (2009), who states that validity is strengthened by openness about how the research is conducted, especially related

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[34] See http://endnote.com/product-details (Accessed 06.11.2017)

to data collection and analysis. In my review process for each paper, the manuscripts were sent to the main informants for feedback, both on how the collected data was structured, and to determine if we shared a common understanding of the findings presented, based on the data. Kvale (2009) has also introduced the term "communicative validity", where the validity is tested in dialogue with the research community, for instance through conferences and by publishing journal articles. The findings are then compared with other relevant research. This has been achieved through presenting five conference papers, attending other academic conferences, workshops and seminars, and writing three journal articles. I have had a continuous dialogue with the research community throughout my doctoral research project. As such, I believe the validity requirements are met by this thesis.

### 3.5.2 Reliability

In general, reliability is about whether the methodology used in the study is well defined, so that others could, in principle, repeat the study and come up with the same results (Justesen & Mik-Meyer 2012; Yin 2009; Tjora 2012). A prerequisite for allowing others to repeat an earlier case study is to document how the case study research is conducted. In this thesis, all data that has been collected and analyzed has been organized and documented. With the use of CAQDAS, a database has been established. Others can then, in principle, receive the project file, review the evidence directly, and not be limited to the results presented in the conference papers, journal articles and this thesis. This increases the reliability of the entire case study.

According to Tjora (2012), it is important to explain how the researcher's own position can influence the research work. To enhance the reliability of the project, it is therefore important for the researcher to reflect on whether they have something in common with or special knowledge on or a commitment towards the informants, and how this may have influenced the collection of data, analysis and results. All informants, first from Kvaerner, subsequently from Aker Solutions and KBR, were assigned to me based on the scope of my research. This was done without any direct involvement from me, as a researcher. My educational background and work experience are mainly in the construction industry, while the informants have experience from and work in the oil and gas industry. Having a lack of knowledge on and experience from the industry I am studying, has resulted in an open-minded and unbiased approach to the collected data. The themes were selected based on the findings from the initial interviews, where the focus was on the use of a PEM and BIM in the case projects, and subsequent discussions with my supervisors. My previous experience of the use of BIM in the construction industry, and knowledge about the principles of a PEM, might have given a certain prejudiced view, but has also contributed to the understanding of findings.

### 3.5.3 Generalization

Paper 1 describes how the findings from the case studies are generalized. In the paper, conceptual generalization, which is a variant of analytical generalization, is introduced. It is

based on the collection and analysis of qualitative data from case projects. The goal has been to develop concepts that capture the key findings, and that are relevant to other cases than those being studied. The main focus for generalization is on a PEM and BIM related to project execution in the oil and gas industry and how these findings can be adapted to the construction industry. The data collected from the case projects have been analyzed using the SDI method and CAQDAS. The result has been insight into the use of a PEM and utilization of BIM, how these are related, and what kinds of effects these have on project execution. Concepts related to project execution with the use of a PEM and BIM have been identified through the main themes. By relating the concepts to relevant theory and research, through the SDI method, and discussing these, fulfills the principles of conceptual generalization.

In addition, moderatum generalization (Payne & Williams 2005) can produce limited generalizations where the scope of what is claimed is moderate and open to change. The goal is to create externally valid and explicit generalizations, even in a moderated form. Generalizations can be moderated in five ways, three of which apply to this research project, as explained in Paper 1. The findings related to a PEM and BIM from case projects in the oil and gas industry should therefore be sufficiently generalizable.

### 3.5.4   Ethics

According to Fellows & Liu (2009: 250), research ethics refers to "the moral principles guiding research, from its inception through to its completion and publication of results and beyond". A good principle is to convey back to participants the results of the research, both out of respect for their time and effort, and because it can provide the researcher constructive feedback for reflection and further research (Tjora 2012). Ethical principles can be broken down into four main areas (Bryman 2012). The first is "harm to participants", where the focus is on minimizing disturbance to the informants, by keeping individuals' identities and records confidential. When parts of the research have been published, I have ensured that individuals are not identified or identifiable. Similarly, Fellows & Liu (2009) state that the confidentiality of information supplied by informants and the anonymity of informants must be respected. Any sensitive information from the informants and sensitive project-specific data has been anonymized. When figures and tables have been used, sensitive text and numbers have been anonymized. The main informants have been identified in the acknowledgements, after receiving their consent. None of the other informants have been named. The next is "lack of informed consent", where the principle is that informants should be given necessary information to be able to make an informed decision about whether they wish to participate in a study or not. Fellows & Liu (2009) also state that informants must be informed about the purpose, methods, and intended possible uses of the research. All informants have been informed about the aim and scope of the thesis, the main focus of each interview, the data collection method used, and the intended use of the data in the research. The next is "invasion of privacy", which is linked to informed consent, and relates to the participant's understanding

of what their participation in the research will entail. According to Fellows & Liu (2009), the research participants must participate in a voluntary way. In this case study research, all informants have volunteered to contribute. The last is "deception", which occurs when researchers present their work as something other than it is. Fellows & Liu (2009) state that the independence of research must be clear, and any conflicts of interest or partiality must be made explicit. The research has been conducted as neutrally and impartially as possible, without any conflicts of interest towards or between the companies, the projects or informants. Ethical considerations have therefore been adequately addressed in this thesis.

# 4   Presentation of papers

The four primary papers (Papers 1, 2, 3 and 4) and the four secondary papers (Papers 5, 6, 7 and 8) are presented in this chapter, to give an overview of their content. The main findings of the primary papers, which build on the secondary papers, are presented and discussed in the fifth chapter, Discussion and conclusions. The papers are included in Appendix B.

## 4.1   Paper 1

Paper 1, "Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry", assesses whether a case study method, based on a framework by Yin (2009), can generate generalizable results, using the case projects in the doctoral thesis as a reference. Initially, the conditions for choosing case study as a research method for the doctoral thesis are verified, using the framework. In case study research, it is the case projects selected and the characteristics of these that determine the generalizability of the results (Flyvbjerg 2006; Seawright & Gerring 2008). The cases selected for this research project need to be similar on the main variables except those related to PEM and BIM. The key characteristics of the case projects are presented, and the uses of PEM and BIM in the two industries compared on important project dimensions.

The possibility to generalize findings on project execution related to the use of PEM and BIM, with the use of case study research, is assessed. The paper introduces conceptual generalization (Tjora 2012) as a way of generalizing in qualitative research and case study research in particular, in addition to moderatum generalization (Payne & Williams 2005), in order to have a broader foundation to generalize on. Furthermore, this paper investigates if there are sufficient similarities between the industries related to project execution and if the findings are applicable to the construction industry. The characteristics of the two industries are compared. The discussion and conclusion summarize the findings. There are several similarities in project execution between the two industries, especially related to the variables PEM and BIM. This increases the possibility of generalizing the findings and increases the relevance towards the construction industry.

## 4.2   Paper 2

Paper 2, "Using a change control system and building information modelling to manage change in design", introduces a change management process and a corresponding CCS. Kvaerner and Aker Solutions has developed CCS, which is a system to store, control, report and follow up project changes and deviations. It was initially developed for use in major projects in the oil and gas industry. The purpose of CCS is to support efficient change processing, with functionality to report, follow-up and archive changes in projects (Kvaerner

2012a). The assumption is that the CCS can be adapted to the construction industry and be used for managing changes in larger multidisciplinary projects.

As a background, this paper investigates what constitutes a change, identifies two main types of changes, and describes how each type can result in four potential outcomes. Data is collected from case projects in the oil and gas industry, primarily through Kvaerner, as EPC contractor, using case study research. The findings are divided into three parts. The first part defines the change management process. The change management process is implemented to control changes in detail engineering, communicate between disciplines and reduce the overall impacts of changes during project execution. This is achieved through five steps. The change management process at Kvaerner is compared to similar processes targeted towards the construction industry, in order to assess the relevance. The literature review identifies a few change management processes that are similar on a principal level, despite there being some clear differences. The second part describes the activities and decisions of the CCS, based on how it is applied in detail engineering at Kvaerner. Based on CCS and collected and analyzed data from the research, a flowchart that visualizes the process from identification to implementation of a change, has been developed. The focus has been on covering the principal parts of the CCS in a sequential manner, which corresponds with the five steps in the change management process. Research on similar change management systems in the construction industry is identified, but the literature review indicates that few are similar to the structure and scope of CCS. The third part describes how BIM is utilized as an integrated part of CCS and how it relates to the parts of the building information models that are frozen. BIM is used by different disciplines to assess if a change is feasible and identify the downstream consequences of the change. The disciplines can go directly into the building information models and highlight their part and interfaces towards other disciplines that is affected by the change. An extract from a building information model can illustrate what the change consists of and who is affected.

In the discussion, benefits and further developments of the change management process and the use of CCS, in relation to those identified in the construction industry, are identified. The use of BIM in conjunction to cost and ability to impact changes in detail engineering, are discussed. The relevance and applicability towards the construction industry is outlined. The conclusion summarizes the key findings and suggests avenues for further research.

## 4.3 Paper 3

The aim of Paper 3, "A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects", is to assess how BIM can be used to report progress in detail engineering through a three-step process. Data is gathered from three case projects in the oil and gas industry, through Kvaerner as EPC contractor, Aker Solutions as engineering and procurement subcontractor, and KBR as engineering and

procurement contractor, using case study research. A flowchart highlighting the key activities in each step is developed and presented.

The first step focuses on the necessary prerequisites and preparations for reporting progress from building information models, using principles defined in the execution level of the PEM. Control objects are introduced, and the way in which status on control objects can define the quality of a building information model is explored. The quality of a building information model can be seen through status on the control objects. When the disciplines reach the relevant quality levels, the object status can be updated accordingly. Progress can be extracted from building information models by exporting statuses on the control objects through the relevant attributes in the associated modeling objects.

The second step focuses on how progress data can be extracted from the building information models and used to report both visual and overall progress. By defining control objects for each discipline and setting statuses on these to reach a desired quality level at each milestone, it is possible to compare and follow up planned progress with actual progress based on BIM. Setting statuses on all control objects enables control of quality and maturity in the building information models. By adding a color code for each status, the control objects can display the status directly, and support the disciplines in identifying what is still being developed and what is frozen in detail engineering. Progress reports based on progress data from the BIM software are developed in order to present the quality and maturity of the design. Actual status on control objects for each discipline can be imported into a spreadsheet software to calculate overall progress. The overall progress report is based on attribute information from the modeling objects to each control object in the building information model. Based on these numbers, the overall percentage complete can be calculated.

The third step focuses on how reported progress from building information models can be connected to activities in an engineering schedule. To be able to report progress based on BIM in the engineering schedule, progress data must be imported into a scheduling software and linked to relevant activities. Progress is reported on the activities through progress on the control object groups. The link from the building information models to the planning tool is made through the progress report. The aim is to identify findings that can be relevant towards the construction industry. This is addressed in the discussion, with a focus on the necessary preparations in the first step. This includes how control objects can be developed. It also includes a comparison between statuses and LOD definitions, and a table that illustrates which LOD should be achieved to each status. The conclusion summarizes the key findings and points to possibilities for further research.

## 4.4   Paper 4

In Paper 4, "Improving collaboration between engineering and construction in detail engineering using a project execution model and BIM", three distinct findings are emphasized.

These are findings that combined can improve collaboration between engineering and construction in detail engineering. Data is gathered from three case projects in the oil and gas industry, through Kvaerner as EPC contractor, Aker Solutions as engineering and procurement subcontractor, and KBR as engineering and procurement contractor, using case study research.

The first part looks at parallelism between engineering and construction, and construction sequence. To execute the project in as short time as possible require a high degree of parallelism. This can be achieved at the milestone at which the engineering deliverables to construction, through relevant parts of the building information models, are frozen and should by definition not be changed. The main contractor has developed a construction sequence that is time and cost efficient for them. The engineering consultant must manage to adapt and design according to that construction sequence, by adjusting milestone requirements. Adding construction sequence is a prerequisite for the objects in the building information models to support fabrication.

The second part focuses on the shift from transactional to relational contracts, and the selection and development of project teams. Traditional contracts often create boundaries that rarely overlap, with clearly defined responsibilities for the parties in a project, and consequences if failures are made. The focus is on transaction between the parties. Establishing a joint venture, as a relational contract, will increase the motivation to collaborate for the contracting parties. The two parties are mutually dependent of both performing. Similarly, an integrated project delivery (IPD) agreement uses a relational structure with jointly shared risk and reward to enable and reinforce collaboration. What will further improve integration is the composition and development of the engineering team. Developing a high-performance team requires focus on four aspects; scope of work, team identity, milestones, and reward and recognition.

The third part assesses how engineering deliverables must be adapted to construction needs. Building information models must be split to support construction. Focusing on specific areas will ensure that fabrication can get the right information at the right time, according to the milestone requirements. To be able to define and control the parts that are sent out for fabrication, the building information models can be split into modules with standardized dimensions, so that they are moveable and able to be transported and lifted by a crane. The main contractor should provide the engineering consultant with constructability recommendations, based on best-practice solutions.

In the discussion, the findings are grouped in process, people and technology, where the first part is related to process, the second part to people and the third part to technology. These are compared to aspects related to integrated design and delivery solutions (IDDS) (Owen *et al.* 2009), to assess the relevance of the findings towards the construction industry. The paper

concludes with a summary of main contributions, limitations and possibilities for further research.

## 4.5    Paper 5

Paper 2 is developed from Paper 5, "Using a change control system and BIM to manage change requests in design". This paper introduces an initial change management process and principles of a corresponding CCS. As a background, this paper investigates what constitutes a change, identifies two main types of changes, and how these can each result in four potential outcomes. Data is collected from case projects in the oil and gas industry, through Kvaerner, as EPC contractor, using case study research. The findings are divided into three parts. The first part defines an initial change management process. Change management is an overall work process that includes the proactive measures required to reduce the volume of changes and to ensure that the cost, schedule and quality are under control. This is achieved through four steps. The initial change management process at Kvaerner is compared to similar processes targeted towards the construction industry, in order to assess the relevance to that industry. The literature review identifies a few change management processes that are similar on a principal level, despite there being some clear differences. The second part describes the principles of a CCS, based on how it is applied in detail engineering at Kvaerner, from identification to implementation of a change. A simple flowchart is developed to illustrate this. Research on similar change management systems in the construction industry is identified. The third part introduces how BIM is utilized as an integrated part of CCS and how it relates to the parts of the building information models that are frozen. In the discussion, benefits and further development of the initial change management process and the use of CCS, in relation to those identified in the construction industry, are identified. The relevance and applicability towards the construction industry is outlined. The conclusion summarizes the key findings.

## 4.6    Paper 6

Paper 3 is developed from Paper 6, "Using BIM to follow up milestones in a project plan during the design phase". The aim of this paper is to assess how BIM can be used to report progress in detail engineering. Data is gathered from three case projects in the oil and gas industry, through Kvaerner, as EPC contractor, using case study research. The first part, BIM and design quality, introduces principles for measuring quality from building information models, based on the PEM developed by Kvaerner. This includes control objects, status definitions and quality levels. The second part, BIM and design progress, compares the project stages in Kvaerner to similar stages in the construction industry, and introduces milestone requirements, based on the PEM. Finally, a connection between control objects, milestones and activities in a project plan is discussed. The conclusion summarizes the key findings and identifies avenues for further research.

## 4.7    Paper 7

Paper 4 is developed from Paper 7, "Improving transition from engineering to construction in detail engineering using a project execution model and BIM". Three distinct findings are emphasized in this paper. These are findings that combined can improve collaboration between engineering and construction in detail engineering. Data is gathered from three case projects in the oil and gas industry, through Kvaerner, as EPC contractor, using case study research. The first part, process, looks at parallelism between engineering and construction and at milestone requirements. The second part, people, introduces joint venture as a contractual arrangement, and the selection and development of project teams. The third part, technology, assesses how building information models must be split in order to adapt to fabrication needs. In the discussion, the findings on process, people and technology are compared to aspects related to integrated design and delivery solutions (IDDS) (Owen *et al.* 2009), to access the relevance of the findings to the construction industry. The paper concludes with a summary of the key findings and possibilities for further research.

## 4.8    Paper 8

Paper 8, "Collaboration and BIM supportive project execution model for the construction industry", introduces a framework for a PEM, developed through the Norwegian research project SamBIM (SamBIM PEM). The background for developing a framework for a common project execution model is to introduce common terminology, increase knowledge and awareness among project participants in how construction projects are to be executed, ensure that necessary decisions are taken at the right time, and ensure good project management and coordination of project participants. A common execution model, that supports the use of BIM, could meet the needs evolving from increased project complexity and demands for collaboration. The research method used to develop the SamBIM PEM is presented. A differentiated methodological approach has been employed, with two main directions: a workshop development approach and a key personnel verification approach. The main part describes the strategic and tactical level of the SamBIM PEM and identifies experiences from the SamBIM case projects. The strategic level describes the phases, stages and milestones. The tactical level describes the logic and structure of stages, and visualizes a flowchart with activities, actors and BIM use. A comparison is made between the phases and stages in the SamBIM PEM and Norwegian and international industry norm initiatives and standards. In the discussion, challenges in developing the SamBIM PEM, the different objectives of the project actors, and divergences between the phases and stages in SamBIM PEM and the initiatives and standards, are all addressed. The conclusion summarizes the findings, underlines a need to test and further develop the SamBIM PEM, and suggests an alignment of the project phases and stages with industry initiatives and norms.

# 5 Discussion and conclusions

The aim of this thesis has been to contribute knowledge on the use of a PEM combined with the use of BIM in major oil and gas projects, and to assess if this knowledge can support improvements in construction projects. This has been addressed through the following research questions: "How are PEM and BIM utilized in major oil and gas projects in the cases studied?" and "How can experiences from the cases studied be relevant for improvements in construction projects?" This chapter starts with an introduction to three interdependent dimensions – process, people and technology, and how the main themes are related to these (5.1). Next, the main research questions in the thesis, and how these have been addressed through the themes and through the research questions asked in the four primary papers, are discussed (5.2). Furthermore, the findings from the basis theme and the three main themes, and how these can support improvements in project execution in the construction industry, are elaborated. This is followed by a summary of the thesis' main contributions to research (5.3) and suggestions for further research (5.4).

## 5.1 Coherence of main themes

Research in the case projects shows that successful project execution requires a holistic approach focusing on three interdependent dimensions: process, people and technology. Process is about development and use of a PEM. People is about collaboration between project actors and development of the engineering team. Technology is about utilizing BIM and BIM-related tools for the management and execution of projects. Process, people and technology can also be identified as categories used to classify challenges and benefits in an integrated design process (Rekola *et al.* 2010). Owen *et al.* (2010) state that improvements in projects in the construction industry result from a holistic focus on process, people and technology. Process is about focusing on integrated work processes. People is about involving people with the right skills, both technical and collaboration skills, and commitment to a team approach. Technology is about having a set of technologies and capabilities for collaboration and automation (Sacks *et al.* 2010a). Furthermore, the lack of development of the construction process and slow adoption of BIM across the industry can be related to the challenge of combining development in process, people and technology (Rekola *et al.* 2010).

A similar framework is the Product-Organization-Process (POP) model, which has been defined as part of VDC, where a combination of products, organization and processes shapes the success of a project (Fischer *et al.* 2017; Kunz & Fischer 2012). Product defines the components and systems of the building. Organization defines organizational groups responsible for engineering and construction. Process defines what the different project participants will do when and in what sequence through activities and milestones. Product in the POP model is based on the development and use of BIM and can therefore be related to

technology. Organization in the POP model is based on collaboration and project team development, and can be related to people. Process in the POP model is about work processes and can be related to process.

According to Ballard (2012), projects can approach optimization through four elements, based on the Lean Construction Institute (LCI) triangle (see Figure 16). This is especially well suited for uncertain and complex projects. As a basis element in the triangle is the operating system to the organization, structured to pursue the relevant Lean principles, and to use the best available methods and tools, both managerial and technological, to apply those principles. The second element is organization, with its structures and flexibility to support people to perform maximum, and at the same time experience their work as value creating. The third element is commercial conditions, such as contracts, that regulate the relationship between the actors in the value chain. The last element in the middle of the triangle is technology, such as BIM, which ensures an efficient flow of information and communication.
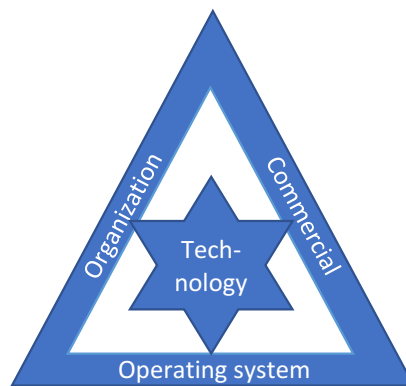


*Figure 16: The LCI triangle. Adapted from Ballard (2012)*

The operating system, which forms the basis of the LCI triangle, is related to process and can be compared to a PEM. Both focus on methods and tools for efficient production and as a basis for continuous improvement. Organization and commercial conditions are both related to people and support these through focus on team performance and conditions for collaboration between actors. Technology, which is located in the middle of the LCI triangle, is based on the use of BIM. Process, people and technology therefore coincide with the key elements in the LCI triangle for project optimization.

Supporting improvements in project execution should therefore be about focusing on both process, people and technology. To substantiate this, and thereby address the research questions, the main themes can be related to these dimensions. The three dimensions, process, people and technology, how these interact and relates to the main themes, can be illustrated in Figure 17 below. Main theme 1 can be seen as an interplay between people and technology, main theme 2 between process and technology, and main theme 3 between

process and people. The findings from the three main themes can then be positioned in the interface between these three interdependent dimensions. The three main themes, which have been chosen based on the use of a PEM and utilization of BIM, therefore relate to all three dimensions. A possible adaption of the findings from the three main themes to the construction industry could therefore support improvements in project execution.
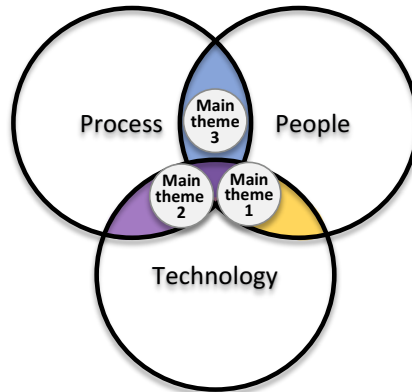


*Figure 17: Main themes and their positioning in relation to the dimensions process, people and technology*

Main theme 1, "Manage change in detail engineering using a change control system and BIM", is primarily related to people and technology. People, because of the human aspect creating the need for change, and subsequently in identification, filtration, evaluation, approval and implementation of changes. Technology, through the use of a CCS and the utilization of BIM. It is secondarily related to process, through the change management process and how that supports the structure of the CCS.

Main theme 2, "Report progress in detail engineering using BIM", is primarily related to process and technology. Process, because of the connection to a PEM, through introduction of control objects in building information models, the use of quality levels related to the maturity achieved at each milestone, and how status on control objects can define the quality of a building information model. Technology, because of the focus on how progress data from building information models can be extracted and used in progress reports, and how progress from building information models can be connected to activities in an engineering schedule. It is secondarily related to people, because of the estimation of number of control objects used in progress reports.

Main theme 3, "Transition and collaboration between engineering and construction using PEM and BIM", is primarily related to process and people. Process, because of parallelism and how an engineering consultant can adapt to the desired construction sequence to a main contractor by adjusting milestone requirements according to a PEM. People, because of the transition from a transactional to a relational contract, with focus on collaboration between the parties, and the mobilization and development of a co-located engineering team. It is

secondarily related to technology, because of the split of building information models, and focus on constructability, to support a desired build sequence.

## 5.2  Research questions and how they are answered through the themes and papers

The research questions asked in this thesis are answered through the themes and the corresponding primary papers (see Figure 18 below). In other words, answering the research questions in the four primary papers therefore answers the research questions in the thesis. The first research question on how a PEM and BIM are utilized in major oil and gas projects through the cases studied, has been addressed by answering the research questions in the primary papers related to the three main themes. The second research question, on how experiences from the cases studied can be relevant for improvements in construction projects, has been addressed by answering the research question in the primary paper related to the basis theme.
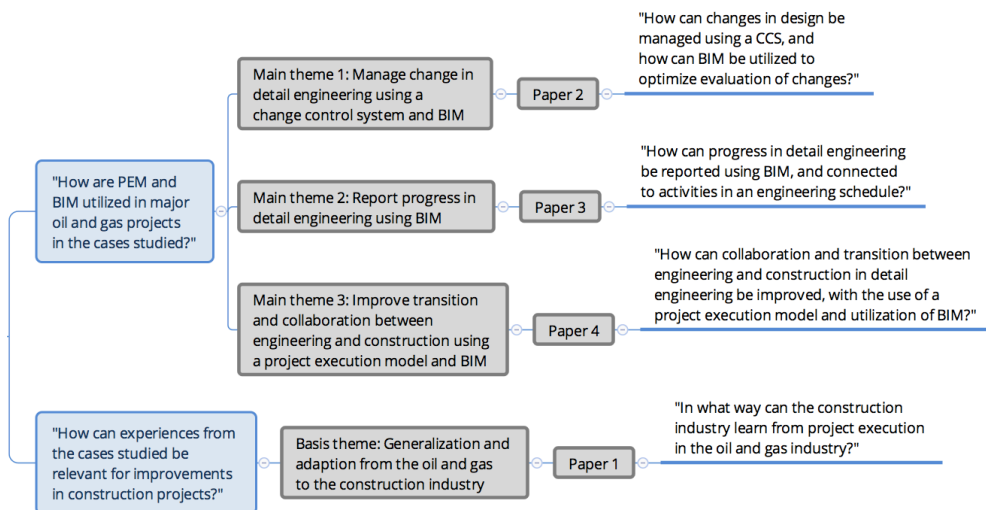


Figure 18: Relationships between research questions, themes and research questions in the papers

In the following sections, the main findings in the basis theme and the main themes are discussed. This includes describing how the themes address the research questions in the thesis, by answering the research questions in the four primary papers.

### 5.2.1  Generalization and adaption from the oil and gas to the construction industry

Paper 1 outlines how we can generalize findings from case study research, and highlights similarities between the oil and gas and construction industry to assess the relevance of the findings related to PEM and BIM towards construction projects. In conceptual generalization, which is a variant of analytic generalization, the goal is to develop concepts (typologies or models) that capture central characteristics of observations and findings, and that will have

relevance to other cases than only those being studied (Tjora 2012). It is a way of generalizing in qualitative research in general and case study research in particular. The SDI method is applied to analyze the collected data and develop concepts related to PEM and BIM and verify these. The goal has been that these concepts have relevance towards project execution in the construction industry. In addition, the aim has been to fulfill requirements in moderatum generalization (Payne & Williams 2005), to have a broader foundation to generalize on. The goal is to create externally valid and explicit generalizations, even in a moderated form. According to the authors, generalizations can be moderated in five ways. These are testable propositions that can be confirmed or rejected through further evidence, and lead to generalizations that have a more hypothetical character. Three of five requirements in moderatum generalization have been fulfilled. This creates a basis for generalization of the findings on project execution related to the use of a PEM and BIM.

There are several similarities in project execution between the oil and gas and construction industries, especially related to the use of a PEM and BIM. Projects in the oil and gas industry are primarily executed as EPC contracts, which are comparable to design-build contracts in the construction industry. Projects in the construction industry are primarily executed using traditional contractual arrangements such as design-build and design-bid-build contracts (Lahdenperä 2012). The principles related to the sequence and structure of the project phases and stages, and use of milestones, are similar. The PEM, as defined in this thesis, comprising both strategic, control and execution levels, is specific to the case projects in the oil and gas industry. Despite this, there are similarities, especially related to the principles of the strategic and control levels. Because of the size and complexity of the oil and gas projects, the building information models contain less information on each object, and most of the information is linked to different support systems. In construction projects, all relevant information is contained within the building information models. Despite being two distinct industries, there are similarities in project execution in terms of the use of a PEM and BIM. While the oil and gas industry is characterized by large projects and international competition, the construction industry has traditionally been characterized by small to medium-size projects with mainly national and local competition. This difference between the two industries is, however, diminishing, as the construction industry moves towards larger and more complex construction projects (Fischer *et al.* 2017; Whyte *et al.* 2016). Both industries are project based with many of the same stakeholders. Companies in both industries depend highly on having a project team with relevant core competences. A PEM is based on codified knowledge from project execution, which makes it easier transferable. The use of BIM is similar on a principal level, except with regard to model complexity and object information.

To summarize, identified concepts can be generalized using conceptual generalization and aspects form moderatum generalization. With the similarities at the industry and project level, the main findings related to PEM and BIM from projects in the oil and gas industry can be relevant to adapt to the construction industry. This answers the research question in Paper 1,

on how the construction industry can learn from the oil and gas industry. The findings also answer the second research question asked in the thesis (see Figure 18 above).

### 5.2.2 Manage change in detail engineering using a change control system and BIM

A change management process and the principles of a corresponding CCS, initially developed by Kvaerner and Aker Solutions for use in major offshore and onshore projects in the oil and gas industry, are introduced in Paper 2. The purpose of the CCS is to support the efficient processing of design changes. Using CCS, engineering teams are able to evaluate implications of design changes in detailed design, both design changes initiated by the engineering team and design changes initiated by the client, as soon as they are identified. This makes it possible for the engineering team, and stakeholders such as the client and contractor, to know in advance if a design change could cause the project to deviate from its original goals, or if special measures have to be considered, before it is implemented. CCS adapts the change management process towards project execution (Kvaerner 2012b).

Based on concepts evolved from the analysis of data from interviews and document studies, using the SDI method, a flowchart that visualizes the process from when the need for a design change is identified to when the design change is implemented, has been developed. The flowchart covers the principal parts of the CCS and corresponds with the five steps in the change management process (see Figure 19 below). Jarratt *et al.* (2011) states that tools and methods that supports the engineering change process can be divided in two groups: those that help manage the workflow or documentation of the process, and those that support engineers in making decisions in the engineering change process. The use of CCS, combined with the utilization of BIM to evaluate design change requests, addresses and combines both these groups. When using BIM in detail engineering, objects are gradually frozen, and should by definition not be changed. Object status is crucial when making decisions about the proper timing of a change in order to reduce its impact. When any of the disciplines or the client needs to change objects in the building information models that are frozen, the changes must be managed. It is at this point that the use of a CCS must be initiated. The reason for developing the flowchart is to illustrate and explain the most important activities and decisions in the CCS, so that it can be adapted and used as a basis for developing a similar system for managing changes.
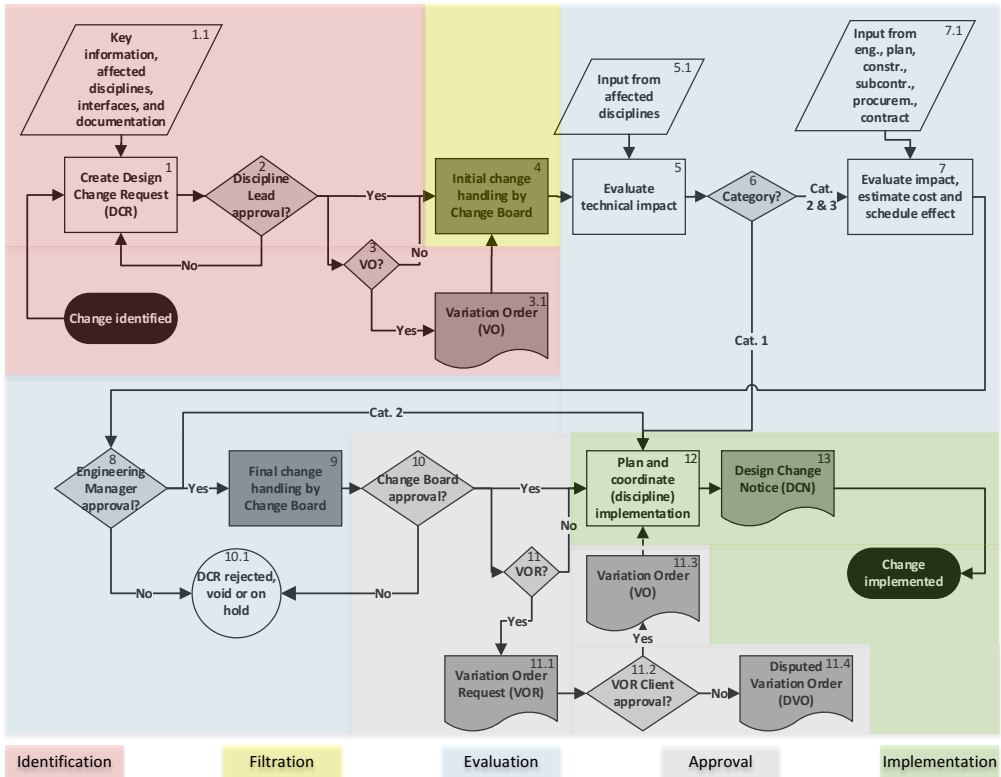
*Figure 19: Principal activities and decisions in the CCS, related to a change management process*

In the first step, "Identification", a potential change in detail engineering is identified with a design change request (DCR). The DCR is registered in the CCS and identified with a tag number, which allows a direct routing to the relevant part of the building information model. In the second step, "Filtration", the DCR will be presented to a Change Board, which efficiently coordinates inputs, and that either rejects or approves further evaluation. Consisting of a change manager, who leads and facilitates, and other relevant managers from key functions, the Change Board has a unique composition that enables a holistic processing of each DCR. In the third step, "Evaluation", the Change Board proceeds to initiate evaluation of impact based on feedback from affected disciplines. BIM is used to identify consequences for the disciplines. DCRs are split in three categories based on their cost and schedule impact, which support more efficient processing, and evaluation at different management levels. In the fourth step, "Approval", the Change Board now has the necessary information, and can decide if the DCR is approved for implementation. Any additional clarifications or formal approvals needed from the client must be processed. In the fifth step, "Implementation", the design change is planned and coordinated by affected disciplines, when there is a decision to implement the DCR.

To summarize, the flowchart that visualizes the principal parts of the CCS, related to a five-step change management process, answers the first part of the research question in Paper 2,

on how changes in design (detail engineering) can be managed. In particular, the third step relates to the second part of the research question in Paper 2, on how BIM can be utilized to optimize evaluation of changes. The findings also address the first research question asked in the thesis (see Figure 18 above).

### 5.2.3   Report progress in detail engineering using BIM

In Paper 3, a three-step process for using BIM to report progress and connect progress to activities in an engineering schedule, is developed, based on experiences from projects in the oil and gas industry. A flowchart has been developed to highlight the key activities in each step (see Figure 20 below). The three-step process has been developed based on concepts evolved from the data collected from interviews and document studies, complemented with observations, using the SDI method.
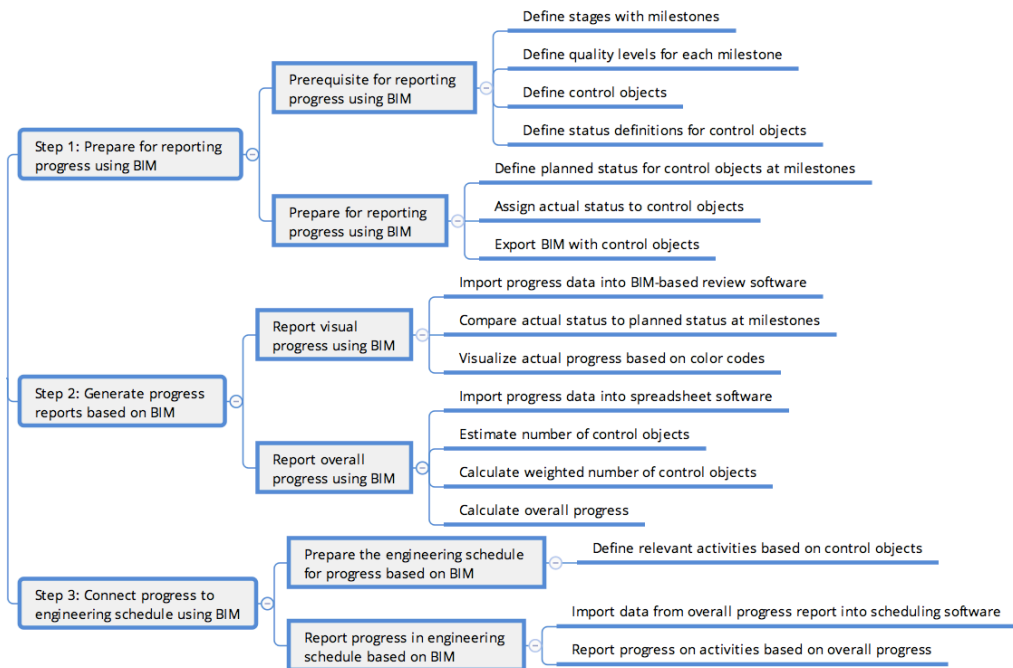


*Figure 20: Using BIM to report progress in detail engineering in three steps*

In the first step, the necessary prerequisites and preparations are made for reporting progress from building information models, using principles defined in the execution level of the PEM. Control objects are introduced for each discipline. A control object consists of several of the same type of modeling objects, or related types of modeling objects in a building information model. These are grouped together for the purpose of comparison and reporting, based on the procurement priority and the criticality to the project. It is possible to get control of the engineering deliverables using statuses that define the quality and maturity of the control objects in the building information models. A higher status must be set for each control object

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at each consecutive milestone in detail engineering, in order to fulfill the desired quality levels. This makes it possible to plan the desired status for all control objects at each milestone, and then compare that to actual status, when the quality level at each milestone is reached. A checklist defines the requirements that must be met for the different statuses for the control objects for each discipline. Progress data are extracted by exporting relevant attributes from the control objects through the associated modeling objects.

In the second step, both visual and overall progress are reported using BIM. By adding color codes to status definitions, progress is reported visually, through status on control objects in the building information models. This makes it possible to see the maturity and quality of the building information models directly. This includes frozen design, which means that the final shape and location of the control objects and all interfaces towards other control objects and disciplines in the relevant parts of the building information models should not be changed. This is probably the most critical status definition. Status is not only quality, but also quantity. Overall progress is reported by aggregating the actual number of control objects and statuses on these, compared to an estimated number of control objects. By weighting the number of control objects towards the different status definitions, the calculation of the overall progress can be more accurate.

In the third step, progress is connected to an engineering schedule using BIM. A prerequisite for this is that the schedule consists of activities that can be related to progress from the building information models. The activities are based on the overall progress to relevant groups of control objects for each discipline and reported directly from the building information models, through the overall progress reports.

To summarize, the first two steps answers the first part of the research question in Paper 3 on how progress is reported from building information models. Based on the first two steps, the last step answers the second part of the research question in Paper 3 on how progress reporting is connected to activities in an engineering schedule. The findings also addresses the first research question in the thesis (see Figure 18 above).

### 5.2.4 Improve transition and collaboration between engineering and construction using a project execution model and BIM

Paper 4 identifies distinct findings in three areas, related to process, people and technology, that combined can improve collaboration in detail engineering between engineering and construction, based on experiences from projects in the oil and gas industry (see Figure 21 below). The findings are developed from concepts evolved from the data collected from interviews and document studies, complemented with observations, using the SDI method.
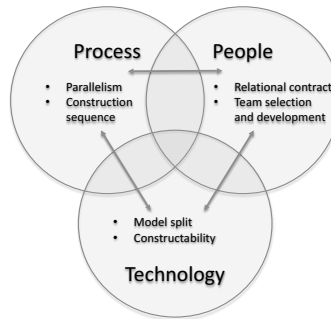
*Figure 21: Improved collaboration between engineering through process, people and technology*

The first area, related to process, is about parallelism and construction sequence. When construction is pushed forward to be executed in parallel with engineering, construction can start as soon as the milestone, where the relevant parts of the design are frozen, is passed. The disciplines have developed the building information models to a quality level at which the relevant control objects, and interfaces between these, are frozen, as defined in a PEM. The main contractor has developed a construction sequence that is time and cost efficient for them. It is important that the engineering consultant manage to adapt and design according to that construction sequence. It is basically to divide the design in accordance with how it is going to be built. The milestones must be coordinated between the engineering consultant and the main contractor, to make sure that the requirements that the main contractor has set for the milestones, in terms of what the disciplines should deliver in detail engineering, when they should deliver it and to what quality, have been adapted to support the construction sequence. This must be reflected through the status the control objects in the building information model should have, to fulfill the desired quality level on each milestone.

The second area, related to people, focuses on the shift towards relational contracts and how engineering teams are selected and developed. In a joint venture, where risks and profits are shared, the incentives for the project to succeed are higher for both parties, because they are mutually dependent on each other. The main advantage of a relational contract, such as joint venture, is its potential to align the objectives of the project team with project objectives. Establishing a joint venture with a common bottom line and common drivers, will increase the motivation to integrate for the contracting parties. If one part is not performing, it has a consequence for the others. It is a contractual arrangement that better prepare for an improved collaboration between engineering and construction. As a relational contract, a joint venture has many of the same characteristics as an IPD agreement. In contrast to a joint venture, where the agreement often is between the main contractor and engineering consultant, the IPD agreement must at least include the owner, engineering consultant and main contractor. As a relational contract, it is not only about a multiparty agreement between key participants, but also early involvement of all parties – typically before engineering starts, and profit tied to the project outcome through shared risk and rewards. Success also depends

on the co-location of the engineering team and the selection of the right people. It is important to mix new and experienced people that have the competence and right skills and can work together, and to match the strength of the people to the risk areas. To be able to develop high performance teams, requires focus on a clearly defined scope of work, creating a common team identity, clearly defined milestones, and reward and recognition when important milestones are met.

The third area, related to technology, focuses on how engineering deliverables must be adapted to construction needs through model split and constructability. Building information models are split in accordance with the requirements of the main contractor, to be able to define and control what is sent out for fabrication. The engineering consultant must concentrate on specific areas to ensure that the main contractor can get the right information at the right time, according to the milestones in a PEM. All disciplines therefore have to make sure that engineering progresses in accordance with fabrication needs, so they get the right information at the right time. The model split is made based on a logical engineering setup, adapted towards the main contractor, so that the different modules can be completed at given milestones, and assembled to a complete construction. With input from the main contractor, the engineering consultant can focus on constructability, based on best practice solutions. This optimizes the engineering process and secures a more efficient construction process.

To summarize, the findings answer the first part of the research question in Paper 4, on how collaboration and transition between engineering and construction in detail engineering can be improved. The findings related to process and technology additionally directly address the last part of the research question in Paper 4, on the use of a PEM and utilization of BIM. The findings also addresses the first research question in the thesis (see Figure 18 above).

## 5.3   Summary and main contributions

In this thesis, I have explored how actors in the oil and gas industry has executed their projects using a PEM and utilizing BIM through the cases studied, and how these experiences can be relevant for improvements in projects in the construction industry. Through case study research, the initial research in the basis theme has shown that it is possible to generalize findings on project execution related to the use of PEM and BIM, using case study research, through conceptual generalization and aspects from moderatum generalization. There are many similarities between the two industries, both at the industry and project level, related to the two key concepts, PEM and BIM. This makes the findings from the case projects in the oil and gas industry highly relevant to adapt to the construction industry. To support improvements in project execution, the detail engineering process and transition to construction must be optimized. The findings from the research indicate that to succeed requires a focus on three dimensions – process, people and technology.

Emphasis on the project execution process through developing and using a PEM is particularly important. The main structure of the PEM, with the strategic, control and execution level, should be used as a basis for adaption towards the construction industry. A special emphasis has been put on the execution level, which also differentiates the PEM towards other knowledge management systems and stage-gate models. However, it is important to agree on the principles related to phases, stages and milestones on the strategic and control level, before adapting relevant parts of the work processes at the execution level. This will be important, both with regards to development and subsequent use in projects. Improving project execution processes also requires utilization of technology, through BIM, to be able to develop and deliver projects "right the first time". Adapting the work processes related to BIM in the execution level of the PEM towards the construction industry, implies defining control objects and status definitions related to control objects. Utilizing BIM in the construction industry requires that BIM is used in all project phases.

The research has identified findings in three main themes, related to the dimensions process, people and technology, which can be relevant to adapt to the construction industry and support improvements in project execution. In general, the contribution to research is not about the individual findings within each main theme per se, but about the combination of key findings from each main theme.

In the interface between people and technology (main theme 1), a flowchart with the key processes in a CCS, supported by a change management process in five steps, has been developed. This can be used as a basis for adaption to the construction industry and developing a system for managing and controlling design change requests in detail engineering. The main contribution to research in main theme 1 is the CCS flowchart. A combination of four key features differentiate the change management process with the use of a CCS, compared to existing research and highlight the benefits of introducing a CCS in the construction industry. The first is how a Change Board efficiently coordinates input for affected disciplines, evaluates impact and approves implementation of change requests. The second is the categorization of change requests based on their cost and schedule impact, and effect on other disciplines, to allow more efficient processing. The third is the focus on a formal client approval process so that design changes are received, evaluated and responded properly from the client, and that design changes from the engineering team are documented and efficiently communicated to the client. The fourth is the use of BIM to assess if change requests are feasible and identify the downstream consequences.

In the interface between process and technology (main theme 2), a three-step process for reporting progress in detail engineering with the use of BIM has been developed. This process can be used as a basis for adaption to the construction industry. The majority of the existing research related to progress management and monitoring progress using BIM, focus on construction and not detail engineering. The main contribution to research in main theme 2

is the focus on detail engineering when reporting progress with the use of BIM, through the combination of the three steps. What further differentiates the three-step process from similar research is the first step, which is a prerequisite for the last two. In the first step, necessary preparations for reporting progress are made in building information models. Here, it is critical to set the right abstraction level. Control objects, status definitions and quality levels are introduced. Control objects are defined based on modeling objects, for each discipline, to reflect actual deliverables. Status requirements for each control object must be set towards each milestone in detail engineering, to reach the desired quality levels. In the second step, visual progress can be reported. This has been elaborated in existing research, but not related to quality and maturity of building information models through the use of object status. By assigning color codes to the statuses, actual status of the control objects in the building information models can be visualized in a BIM-based review software. This is a prerequisite to be able to report a realistic overall progress using BIM. Here, it is essential to set a realistic estimate of the number of control objects. Furthermore, calculating the weighted number of control objects for each status is also important for a reliable overall progress for each discipline. The reported progress is connected to the engineering schedule in the third step. Different approaches to this have been elaborated in existing research. An alternative, as presented here, is based on control objects. To be able to report progress directly from the building information models, activities in the schedule are defined based on control objects for each discipline. This is the same abstraction level as the overall progress report.

In the interface between process and people (main theme 3), a combination of three aspects increases collaboration between engineering and construction in detail engineering. This combination is also the main contribution to research in main theme 3, and can be used as a basis for adaption to the construction industry. The first, focusing on process, is related to parallelism and construction sequence. Reducing total delivery time and cost of a project through parallelism between engineering and construction is not new to research. What is emphasized here, is the importance of initiating transition from engineering to construction at the milestone at which the relevant parts of the building information model are frozen. To achieve this, it is important that the engineering consultant can adapt to a desired construction sequence to the main contractor, by adjusting their milestone requirements in detail engineering to deliver "right the first time". The second, focusing on people, is related to the transition from transactional to relational contracts, and the importance of selecting and developing the engineering team. This has been elaborated in existing research. The scope here has been on a relational contract through a joint venture where the two parties are mutually dependent of both performing, and share profits on the bottom line in a percentage distribution. Similarly, an IPD agreement uses a relational structure with jointly shared risk and reward to enable and reinforce collaboration. It has been emphasized that to succeed requires selection of the right people from both parties in the engineering team, and development of a high-performance team, through four aspects. The third, focusing on

technology, is related to model split towards construction and constructability. Both have been elaborated in existing research. The focus here has been on further adapting the design towards fabrication. It is emphasized how the engineering team can split building information models according to the requirements of the main contractor, to be able to define fabrication assemblies and control what is sent out for fabrication. To succeed, the engineering consultant should focus on constructability, with input from the main contractor, which optimizes the engineering process and secures a more efficient construction process for the main contractor.

## 5.4   Suggestions for further research

Further research will focus on adaption and potential implementation of the findings from the case projects in the oil and gas industry to projects in the construction industry. The focus will be on the Norwegian construction industry, but the findings will be relevant to other countries with similar industry characteristics to those specified in 1.3. To be able to adapt and implement the key findings from the research to construction projects, an increased focus on learning from other industries is needed. In Norway, key actors in the construction industry, through the Federation of Norwegian Construction Industries (BNL),[35] recently published a digital roadmap (BNL 2017). As part of this, the change of business models, as a consequence of digitalization,[36] is discussed, with reference to other industries, such as the oil and gas industry. Digitalization and learning from other industries could lead to an increased demand for the key concepts in this thesis and the research conducted on the case projects in the oil and gas industry, and possible adaption of the findings identified in all three main themes. To support this, further research should be conducted, preferably on ongoing and upcoming projects in the construction industry.

At an organizational level, a PEM for use in construction projects should be developed. The focus should not only be on defining the strategic and control level, but also on exploring the possibilities at the execution level in the PEM, and gaining experiences through the use in projects. Through the SamBIM research project, a framework for a PEM, corresponding to a strategic and control level in the PEM, has been developed (see Paper 8 in Appendix B). Despite being developed for the Norwegian construction industry, this can also be used as an inspiration for the initial development and adaption to the construction industry, not only in Norway but in other countries as well.

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[35] BNL is a business and employer policy organization for companies in the Norwegian construction industry. See http://www.bnl.no/dette-er-bnl/english/ (Accessed 21.11.2017)
[36] Digitalization can be defined as the "development and deployment of digital technologies and processes" (WEF 2016: 24)

Based on the flowchart and corresponding description introduced in main theme 1, further research should focus on developing a mock-up of a CCS, a prototype with key system functionality, as the first step towards developing a CCS for the construction industry.

Further research in main theme 2 should focus on necessary preparations for reporting progress using BIM. This include developing a set of control objects with corresponding status definitions and checklists for all main disciplines for use in detail engineering. Furthermore, a progress report should be adapted towards the construction industry to be able to plan and extract the number of control objects and status from the building information models. Finally, a schedule template, with a set of activities based on control objects for each discipline, for use in an engineering schedule, should be developed, so that it will be possible to measure progress on these, based on input from building information models.

In main theme 3, a natural focus for further research will be a possible adaption of the specific findings towards projects in the construction industry. An initial scope for the engineering contractor should be to support a desired construction sequence for engineering in collaboration with the main contractor, initiate a relational contract between the engineering consultant and main contractor, and prepare for splitting of building information models to support fabrication and construction.

As part of further research, the results presented in this thesis have already started to be adapted and implemented in construction projects. I have been engaged by Statsbygg[37] as a consultant to support their digitalization initiative, called Digibygg.[38] The focus of the engagement is to implement findings from the main themes in the thesis, as part of sponsored Digibygg options in selected projects. This will be an important arena to implement and further develop the findings and gain valuable experiences on how these can support improvements in execution of projects in the construction industry. Findings from main theme 2 have already been adapted and implemented in the first Digibygg project.[39]

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[37] Statsbygg is a building commissioner, property manager and property developer, and the key advisor in construction and property affairs for the Norwegian government. See http://www.statsbygg.no/Om-Statsbygg/About-Statsbygg/ (Accessed 06.11.2017)

[38] The goal of Digibygg is to advance the construction industry and enhance the use of digitalization and technology in construction projects. Statsbygg will initially use a selection of smaller projects as Digibygg pilots to gain experience, before targeting larger projects. See http://www.statsbygg.no/Prosjekter-og-eiendommer/Byggeprosjekter/Digibygg/ (Accessed 06.11.2017)

[39] "The project will provide practical experience with status setting and progress reporting from the BIM model as a basis for assessing more comprehensive implementation in future projects." [Translated from Norwegian] See http://statsbygg.no/Nytt-fra-Statsbygg/Nyheter/2017/Forste-spadetak-for-Digibygg-pilot/. (Accessed 06.11.2017)

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**PhD: Questions for further research — Øystein Mejlænder-Larsen 16.06.07**

## "Using a 3D model (BIM) to follow up milestones in a project plan during the design phase"

### Status
- What are the benefits and possibilities of adding status to (control) objects in the model?
- What is the relation between quality level (control object) and status (object)?
  - What are the differences between quality levels definitions and status definitions (SD-SS)?
- At what milestones in detailed design are quality level (status) reported?
  - Detailed design (detail engineering): 2A, 2B, 2C, 3A
- Are status definitions updated after demerger?
- Do you have an overview of typical control objects (discipline level)?
- Are control objects defined in PEM?
  - Should all control objects be frozen at M2C?

### Checklist
- Are there checklists on control objects AND objects?
  - Are the checklists related to milestone requirements?
  - Are the checklists related to quality level and status?
- Do you have examples of typical check lists (with control questions) for a discipline in the design phase?

### Model > Project plan
- How are quality level/status on control objects exported from the model and imported into the planning software?
  - Why different systems?
- Is Safran used by Kvaerner and Primavera by Aker Solutions?
  - Does both have the same functionality with regards to importing status from model to control objects?
- To what extent are activities in the project plan (in the design phase) defined with control objects?
  - How are activities related to milestones?

### Project plan
- How are status on activities (based on control objects) in the project plan reported (from the project plan)?
  - How to follow up activities that are behind (status/quality level not fulfilled on relevant milestone)?
  - How many activities in the project plan can be reported from the model (%)?
- Is the goal to report up to 50% of progress from model?
  - What are the main challenges of increasing this?
- Is the count report (tellerapport) / count curves (tellekurver) used as a supplement or replacement for reporting object status (with status codes / color codes)?
  - To what extent is this used?

### Other methods
- Do you have examples of count report / count curves that shows status increase (preferably for different disciplines)?
- Is a punch list created, and how is this followed up (%)?

## "Improving transition from engineering to construction using a project execution model and 3D model (BIM)"

### Parallelism
- Is parallelism defined as integrating fabrication in design?
  - Is concurrent engineering (CE) also used as a term for parallelism?
- How does parallelism affect number (and distribution) of work hours?
- How does parallelism affect drawing production?
- What determines how early in detail engineering the contractor is involved?
- In what way does PEM support parallelism?
- Does parallelism improve or hinder collaboration/transition from engineering to construction?

### Build sequence
- How does the build sequence to the contractor differ from the engineering sequence to the contractor?
- How must (typically) design be altered and model (development) rearranged, by the engineering subcontractor, to fit into the desired planning and build sequence to the contractor?
  - Does it differ between Kvaerner and other contractors?
- Is the principle behind "right the first time" that a certain quality level is achieved to a certain point in time?
  - To what extent is this operation supported by PEM?

### "Right the first time"
- How is "right the first time" related to milestone requirements?
- Does PEM support "right the first time" by defining milestone requirements and associated discipline checklists to all stages in each project phase?
- Are differences identified and are additions added to milestones to engineering subcontractor to meet requirements to contractor?
  - How does this affect the requirements towards the engineering subcontractor?
  - Does engineering subcontractor use own PEM but with additions?
  - Only engineering subcontractor actor that needs to adjust milestones or also contractor?
- How is "right the first time" related to parallelism?
  - Does engineering subcontractor support parallelism and "right the first time"?

### Joint venture
**Contract**
- What are major contractual drives to engineering subcontractor and contractor?
  - How does a joint venture support parallelism and "right the first time"?
  - Why does these differ?
- What are the main incentives to establish a joint venture?

**Project team**
- How to select key personnel?
- How to secure that key personnel are part of the next project?
- What measures are taken to secure motivation of the project team?
- How to ensure sufficient competence and experience of the project team?

### Fabrication assemblies
- How is the model split for fabrication (and construction)?
  - How is this related to build sequence?
- How does PAV and FAS work?
- How does equipment (purchase orders and criticality) relate to PAV/FAS?

# Appendix B: Papers

## Paper 1

Mejlænder-Larsen, Ø. (2015). **Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry.** *Procedia Economics and Finance*, *21*, 271-278.

## Paper 2

Mejlænder-Larsen, Ø. (2017). **Using a change control system and building information modelling to manage change in design.** *Architectural Engineering and Design Management*, 13(1), 39-51.

## Paper 3

Mejlænder-Larsen, Ø. (2019). **A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects.** *Engineering, Construction and Architectural Management* (Accepted for publication 10 April 2018).

## Paper 4

Mejlænder-Larsen, Ø. (2018). **Improving collaboration between engineering and construction in detail engineering using a project execution model and BIM.** *Journal of Information Technology in Construction (ITCon)*, *23*(16), 324-339.

### Paper 5

Mejlænder-Larsen, Ø. (2015). **Using a change control system and BIM to manage change requests in design.** *Proceedings of the 32nd International CIB W78 Conference*; 549-558.

### Paper 6

Mejlænder-Larsen, Ø. (2015). **Using BIM to follow up milestones in a project plan during the design phase.** *WIT Transactions on the Built Environment 2015;* Vol. 149, 97-106.

### Paper 7

Mejlænder-Larsen, Ø. (2016). **Improving transition from engineering to construction using a project execution model and BIM.** *Proceedings of the CIB World Building Congress 2016*; 1, 540-551.

### Paper 8

Mejlænder-Larsen, Ø., Flyen, C., & Lie, B. E. (2016). **Collaboration and BIM supportive project execution model for the construction industry.** *Proceedings of the 41st IAHS World Congress,* ISBN: 978-989-98949-4-5.

## Paper 1

Mejlænder-Larsen, Ø. (2015). **Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry.** *Procedia Economics and Finance*, *21*, 271-278.

8th Nordic Conference on Construction Economics and Organization

# Generalising via the case studies and adapting the oil and gas industry's project execution concepts to the construction industry

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**Abstract**

The aim of this paper is to explore whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment, based on case study research. Besides, sufficient similarities between the two industries were assessed and the applicability of the findings from the cases in the oil and gas industry was assessed. The selected cases (the ongoing projects) have several principal similarities, but the extents of use differ. The project execution model (PEM) of the oil and gas industry is based on codified knowledge from project execution, which makes it easier to transfer such models to other industries. The use of 3D design environments or building information modeling (BIM) in the construction industry is similar to the use of PEMs in the oil and gas industry but BIM differs on model complexity and object information. The findings indicate that it may be possible to develop generalizable project execution concepts in the oil and gas industry by using the conceptual generalisation theory. Indeed, it is herein proposed that the high-similarity between the variables related to PEM and BIM enables the transfer and adaptability of PEM-based concepts to the construction industry.

## 1. Introduction

The construction industry is a large and value-creating industry, but it suffers from too many building defects and often too high construction costs. Annual costs related to the repair of building damages in Norway, as a result of

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defects during design and construction, probably represent 2-6 percent of the annual investment costs for new-build projects (Ingvaldsen, 2008). In recent years, the construction industry has seen an increase in larger and more complex building projects. Larger projects, higher complexity and increased risk in these projects imply that both building owners and contractors should focus on the professional management of projects, increased interaction between actors in value chains and the increased utilisation of available and innovative technology. However, the construction industry is one of the least R&D intensive industries in Norway (Reve & Sasson, 2012). According to Bygballe and Ingemansson (2011), poor technological and economic developments may partly be due to the state's low and fragmented involvement, i.e. several ministries share responsibility for the construction industry, in contrast to only one ministry being responsible for the oil and gas industry. In part, the low level of the public and private funding of construction-related research has its limiting consequences.

In turn, the oil and gas industry has managed large and complex projects and invested heavily in the development of new technology over the past 40 years. The Norwegian oil and gas industry has gained the international recognition for project leadership, PM and technology utilisation.

It is herein foreseen that the construction industry would benefit from gathering knowledge and learning new lessons from other industries with relevant experience in executing large and complex projects. The case in point involves many similarities in project execution between the construction industry and the oil and gas industry in terms of project phases, actors, management principles and technology use. Overall, the author's PhD study involves the exploration on the successful management of major oil and gas projects by one of Norway's largest engineering, procurement and construction (EPC) contractors, Kvaerner, based on the use of a project execution model (PEM[A]), combined with the utilisation of the 3D design environment[B], corresponding to building information modeling (BIM[C]) in the construction industry. Success is measured in terms of right quality, as planned and on time. The objective of a PEM is to secure predictability in project execution by using a standard methodology well known to each project team. Multidisciplinary understanding and common goals through management and execution processes are the prerequisites to avoid rework and instead deliver "correct the first time" (Kvaerner, 2012b). The utilisation of the 3D design environment is crucial for successful implementation of PEM in a project, combined with structured (object related) information, planning, change management and document management.

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**Nomenclature**

A       A project execution model (PEM) reflects a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones to ensure predictable project execution (Kvaerner, 2012b). It is mainly based on the Project Integration Management knowledge area defined in PMBOK Guide (PMI, 2013).

B       A 3D design environment refers to a multi-discipline and object based 3D design software integrated with a number of information systems that serves as the main source of information for engineering and construction. The main purpose is to improve the coordination and consistency between the disciplines responsible for the design in the project (Kvaerner, 2012a).

C       Building Information Modeling (BIM) can be defined as a digital representation of physical and functional characteristics of a facility. It is a shared knowledge resource for information about a facility and forms a reliable basis for decisions during its life cycle – from concept to demolition (NBIMS, 2007).

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Via many case projects, the PhD study aims at identifying solutions and practices within process and technology areas that could be adapted to the construction industry and, thus, contribute to higher effectiveness in building processes. In turn, the aim of this paper is to re-use the same case projects as a reference to explore the theoretical basis for generalising based on such case studies and to assess whether it is possible to generalise findings on project execution and the use of PEM and the 3D design environment in the oil and gas industry. Furthermore, the sufficiency of similarities in project execution between the two industries is investigated and the adaptability of such findings to the construction industry is assessed. The working hypothesis is that case-based findings on project

execution in the oil and gas industry can be generalised and that findings related to the use of PEM and the 3D design environment (BIM) can be adapted to the construction industry.

## 2. Case study research

The choice of an applicable research method is important when doing social science research. Herein, the possibility to generalise based on case study research is assessed. The choice of the case studies is based on Yin's (2009) framework and therein the three conditions for distinguishing different research methods, i.e. the form of the research question, the extent of control a researcher has over actual behavioural events and the degree of focus on contemporary events. The first condition is to classify the type of research question being asked. "How" and "why" questions are explanatory, dealing with conditions followed over time, instead of incidents. The research questions for the PhD study as a whole are "How can the construction industry learn from the oil and gas industry in terms of executing projects more efficient, with the use of project execution models?" and "How does the use of the 3D design environment (BIM) support this?" The research question starts with "How", because case projects are followed over time. This condition will favour the use of experiments, case studies and histories as research methods. The next condition is the extent of control over and access to actual relevant behavioural events, i.e. case projects. In turn, the author is only observing case projects over time, without any formal role and manipulation. These two conditions still favour the use of case studies and histories as research methods. The last condition is based on the focus on contemporary events as opposed to historical events. The focus of the author is on examining contemporary events and the follow-up of the selected ongoing projects within the two industries, through various phases, which makes case study a preferred option. Together, these three conditions only favour case studies to be relied upon.

## 3. Case selection

Flyvbjerg (2006) states that generalizability relates to the question of case selection and that the right strategic selection of cases can increase the generalizability of case studies. According to Seawright and Gerring (2008), there are two objectives in case selection in case study research. That is to find a representative sample and to aim for variation on the dimensions of theoretical interest, within a relevant population. Among the seven case study types, "most similar" cases provide the strongest basis for generalisation. "Most similar" cases must consist of at least two cases. The chosen cases should be broadly representative for the population of interest, and ideally, similar on all measured variables except the variables of interest. In turn, the case projects in the overall study have several principal similarities, but the extents of the use of the PEM and the 3D design environment (BIM) in project execution differ between the oil and gas industry and the construction industry.

In the oil and gas industry the contract is mainly EPC where only one, two or all three areas can be subcontracted. The author has access to the three ongoing projects at Kvaerner as the cases in the oil and gas industry. Kvaerner has initially selected the two cases, i.e. the delivery of the topsides for the two production platforms in the North Sea, both executed as the EPC contract and one with engineering on the subcontract. The last case involves the modifications and the projects on the onshore gas facility on the west coast of Norway, executed as the EPC contract, with engineering on the subcontract.

An EPC contract in the oil and gas industry corresponds to a design-build contract in the construction industry where the engineering and construction services are contracted by a single builder or contractor. Design-build and design-bid-build, where engineering and construction are contracted separately, are the most common contracts in the construction industry. The author has access to up to three case projects in the construction industry, related to the research project "Collaboration in the building process - with BIM as a catalyst" (Forskningradet, 2014), funded by the Research Council of Norway. The industry partners have selected the cases, i.e. the commercial buildings and the ongoing projects located in and around Oslo, via the design-build contract and the design-bid-build contract.

Principally, project phases and sequences in project execution can be grouped according to the phases in construction projects, defined in ISO 22263:2008 (ISO, 2008), which starts with a pre-project phase, followed by a

pre-construction phase, a construction phase and finally a post-construction phase. Within these principal groups of phases, the number of phases and the name of these differ for the two industries. Despite these differences, the sequence and structure of the project phases in the cases in the both industries are similar, operating with the delivery milestones connected to each phase.

Kvaerner manages large and complex onshore and offshore EPC projects in the 6 to 10 billion NOK range. If Kvaerner is going to compete in a global market, they are highly dependent on using a PEM. The extent of the use of Kvaerner's PEM depends on the types of projects as well as the composition, preferences and competences of the project team. Case projects differ from each other in these respects. In addition, the use of the PEM depends on the use of subcontractors and to the extents that they use their own PEMs, respectively. The more similar the latter are to Kvaerner's PEM, the more streamlined the process becomes in terms of detailed deliveries and milestones. In the two cases, Kvaerner has subcontracted the engineering to Aker Solutions. In the last case, Aker Solutions supplements the engineering resources to Kvaerner. Namely, the two companies were separated in 2011, but they use more or less the same PEM (and Aker Solutions is focusing on the engineering and procurement part).

The 3D design environment is used in Kvaerner in all the cases and towards some of the subcontractors. By project, the use and outcomes depends on the scope of subcontracted engineering and the extents to which the respective subcontractors are actually using it. This often depends on experience and the client's contractual requirements. From the systems perspective, the size and complexity of the 3D model and information related to each object are much greater in the oil and gas industry than in the construction industry. This results in a large number of connected support systems in order to process the large amount of information. The 3D model itself therefore contains less information about each object, because most of the information is defined in the corresponding support systems – connected to each object with unique tag numbers. In the construction industry, all relevant information is contained within each object in the BIM. In the cases, the use of the BIM differs between the traditional approach to BIM where there are few requirements in the contract and the ambitious requirements within the engineering team and towards the contractor. In the both industries, a client can have specific requirements related to the delivery, quality and structure of the 3D design environment or the BIM, in addition to requirements towards traditional drawings. Clients with their BIM requirements give incentives for the extended use of the BIM in projects.

Despite some variance, the case projects are similar along many of the main project dimensions, except the use of the PEM and the utilisation of the 3D design environment or the BIM. This fulfils the basic requirements for "most similar" cases, which is a viable starting point for being able to generalise. Having cases with the different utilisation of these dimensions opens the possibility to analyse the impacts that the PEM and the 3D design environment or the BIM have on project execution.

## 4. Generalisation in case study research

It is stated that the generalisation of findings of qualitative research in general, and especially those of case studies, is restricted. Data collection, such as participant observations and interviews with a small number of individuals, makes it impossible to know how findings can be generalised to other settings (Bryman, 2012). This is also known as the challenge with "external validity" (Yin, 2009) of research findings and the problem of knowing if the research findings are generalizable beyond the case study researched. This has historically been a barrier for doing case studies, especially the single-case ones. Many of the critics come from the natural sciences, where case studies (qualitative research) have been compared with surveys (quantitative research). In the natural sciences, statistical generalisation is the basis for most generalisations and also the basis for generalising in survey research (Yin, 2009). According to Bryman (2012), there are two kinds of generalisations in qualitative studies; analytic generalisation and moderatum generalisation.

Yin (2009) states that analytic generalisation is the basis for generalisations in case study research where the goal is to generalise results to a broader theory. A previously developed theory is used as a template to compare the empirical findings in the case study research. In the most basic form, replication can be claimed if two or more cases support the same previously developed theory. Analytic generalisation can be used whether the case study involves

one case or several cases. According to Tjora (2012), the goal with qualitative research is to develop knowledge to a phenomenon, which can be tested through concept/theory development. The author introduces herein conceptual generalisation, which is a variant of analytic generalisation and closely related to grounded theory. The goal is to develop concepts (typologies or models) that capture the central characteristics of observations and findings, and that have relevance to other cases than only those being studied. The results from the research can be related to other research and a relevant theory to support a greater validity and generalizability. In most cases, theory development by generalising results to a broader theory is not an absolute criterion. The theoretical discussion and development of concepts are often sufficient to achieve conceptual generalisation (Tjora, 2012).

An alternative to analytic generalisation is moderatum generalisation. Payne and Williams (2005) claim that qualitative research methods can produce limited generalisations where the scope of what is claimed is moderate and open to change. These can be testable propositions that can be confirmed or rejected through further evidence and, thus, lead to generalisations that have a more hypothetical character. The goal is to create externally valid and explicit generalisations, even in a moderated form. Generalisations can be moderated in five ways. The first is whether the findings of a study are limited to certain types of phenomena, which defines how widely applicable the findings are. The second is about the limitations of time periods where findings related to current conditions are likely to be more valid than a claim about future conditions. The third is about how detailed the study has characterised the topic and how it defines the level of precision from very precise to more approximate. The fourth is about limiting claims to basic patterns or tendencies so that similar studies produce closely related but not identical findings. The fifth is about how the condition for generalisation is related to the ontological status of the phenomena that are researched, where there are stronger claims about some phenomena (like social structures) than others (like cultural features).

The conceptual generalisation is herein chosen. It gives the most applicable tools to generalise from the ongoing case study research, based on the collection and analysis of the qualitative data from the case projects. The stepwise-deductive-inductive (SDI) method (Tjora, 2012) is being used. The principle of this method is to work stepwise from data to concepts or theories (inductive) and verify these theoretical outcomes to the more empirical ones (deductive). The collected data are transcribed and the computer assisted qualitative data analysis software (CAQDAS) is used to develop the "empiric-close" coding that reflects the contents of the text. The codes are grouped into the categories and used as a basis to finally develop concepts. This is similar to what Halkier (2011) has described as "category zooming", as one of three ways to generalise qualitative data. In turn, the author describes a three-step process, from coding and categorizing, through the tracing of systematic relationships between categories and finally aiming for a tightly connected synthesis by conceptualizing. The collected data from the case projects at Kvaerner are analysed. Insight is gained on how the projects are designed and executed using the PEM and the 3D design environment (BIM), how these two areas are related to each other and what the effects the 3D design environment or the BIM has on project execution. By analysing the data using the SDI method, the purpose is to identify concepts within defined themes related to project execution with the use of the PEM and the 3D design environment or the BIM. Relating the concepts to a relevant theory and research as well as discussing these will fulfil the principles in conceptual generalisation.

The author also aims at fulfilling several aspects of moderatum generalisation. The findings of a case study are limited to certain types of phenomena. This relates to what George and Bennett (2005) have identified as "building block", one of six types of theory-building research objectives, which study types or subtypes of a phenomenon. The phenomenon researched is the project execution at Kvaerner, with a focus on the PEM and the 3D design environment as the subtypes. The generalisation is likely to take place more easily through the working with the subtypes with the smaller and well-defined scope in comparison with the larger types and a broader scope. It seems that the working with a subtype of a phenomenon is also an effective strategy for potential theory development, because the development of a (sub)theory for a subtype is more manageable in comparison with the development of a general theory for the entire phenomenon. The author is focusing on the findings related to the current conditions because the cases involve the ongoing projects. The research on ongoing projects corresponds to what Payne and Williams (2005) define as "social structures", having a high ontological status. This can make it easier to make stronger claims about findings. When it comes to the level of detail in the research, the aim is external validity,

which depends on what is called "thick description". This refers to the richness of the data collected and the detailed description on how it is collected (Payne & Williams, 2005). This author is collecting a large number of data from many different sources, mainly from the oil and gas industry. The primary source of the data collection is the documentation and the interviews. The necessary background information and the detailed descriptions are accessed through the relevant company and project documentation. The interviews with the resources in the key positions are conducted both within the company and inside the cases so that any variance between the theory and the practice in the projects can be identified. By interviewing more than one resource on each main theme, the quality of the gathered data increases and competing explanations are pinpointed for further investigation. The secondary source of the data collection involves the observations. Through the observations at the project meetings and on site, the author is comparing his own observations with the explanations from the documentation and the interviews.

## 5. Generalisation between industries

A possibility to generalise from the oil and gas industry to the construction industry depends on the similarities between the two industries. The oil and gas industry, with its large projects competing in a global market with global competitors, is somewhat different from the construction industry, with small to medium projects and competing in a local market with mainly local competitors. Nevertheless, the variances between the key project execution characteristics in the oil and gas industry and those in the construction industry turned out to be relatively small. The both industries are project-based with less control of its environment, compared to other industries. The primary outputs involve unique projects. Major projects involve several stakeholders, including a client, an end-customer (user), a main contractor, sub-contractors, specialist suppliers and advisors/consultants, which form temporarily coalitions during the duration of the project. Relationships between these stakeholders vary, depending on project types and contract types (Barlow, 2000).

Successful project execution depends on a project team that has relevant competences and can collaborate in order to solve problems inherent in large and complex projects. This is mainly based on what Lampel (2001) calls "core competencies", which means the ability to assemble a pool of resources according to the demands of each particular project. There are at least two essential core competences, i.e. engineering know-how and technical competence. Engineering know-how includes programmable activities that are broken down, analysed and described in detail, such as the use of a PEM. It also includes tacit activities, such as identifying crucial knowledge and applying it to where it is needed, learning from own experience and innovating solutions for problems that occur. A key aspect of a PEM is that resources with variable competences in a project team are able to execute their work in a predefined sequence and quality. In turn, technical competence is related to the use of technological assets such as the 3D design environment or the BIM and other support systems (Lampel, 2001). There is one (different) project team for each case project, but the desired composition of all the teams and the aggregated competences are somewhat similar. As a minimum, a project manager and/or a PM team should have necessary experience and a competence to utilise resources and find solutions to challenges that occur. There is also a goal in both industries to have project teams that consist of resources that use best practices from earlier projects and relevant software systems for managing and executing projects.

Table 1. Characteristics inherent in the case project execution in the oil and gas and construction industries.

| Characteristics | Oil and gas industry | Construction industry | Degree of similarity |
| --- | --- | --- | --- |
| Market | Global | National/local | Low |
| Project size | Large projects | Small to medium projects | Low-medium |
| Execution | Project based | Project based | High |
| Stakeholders | Clients, end-users, contractors, suppliers, consultants | Clients, end-users, contractors, suppliers, architects, consultants | High |
| Project team composition | Engineering know-how and technical competence | Engineering know-how and technical competence | High |

It is herein hypothesised that the more similar the industries are related to project execution and more specifically on the variables related to the PEM and the 3D design environment or the BIM, the more relevant the findings from the oil and gas industry are towards the construction industry. Knowledge transfer between organisations depends on the degree of complexity and whether the knowledge can be codified. Codified knowledge is structured according to a set of easily communicated identifiable rules. Knowledge that is relatively easily codified is easier transferred than knowledge that is embedded in the culture and work principles of an organisation (Barlow, 2000). The development of the PEM as a methodology is based on the codified knowledge through the experience and the best practices in the project execution. It has been developed over several decades based on the experience of delivering the major offshore and onshore facilities. The PEM focuses on predictability in project execution and operations with defined management and execution work processes, deliverables, decision gates and interfaces so that project goals on quality and cost efficiency can be achieved (Kvaerner, 2012b). It is herein assessed that the principles in this methodology and the process description could be highly relevant for the construction industry. Typically, 3D design environments integrate product information with process information from enterprise-wide information systems. Recently, similar BIM based systems have been implemented in the construction industry. These tools enable visualisations of process and product status in order to deliver information to workers in construction environments (Sacks et al., 2010).

## 6. Discussion and conclusion

The starting point for this paper was the verification of the author's PhD study as the case study research, by relying on Yin's (2009) framework. Cases and their characteristics are essential for being able to generalise (Flyvbjerg, 2006; Seawright & Gerring, 2008). In this study, the chosen cases should be a "most similar" case study type, and thereby similar to the main variables except those related to the PEM and the 3D design environment or the BIM. The key characteristics of the case projects have been reported upon including the comparative use of these two variables along the key dimensions in the two industries. In most cases in the both industries, engineering was subcontracted, by either the contractor (EPC and design-build) or the owner (design-bid-build). The sequence and structure of the project phases and the related milestones are similar. The PEM was used in all the case projects in the oil and gas industry and the 3D design environments contained less information on each object, and most of the information was defined in the support systems. In the cases in the construction industry, all the relevant information was contained within the BIM. Despite being cases in the two industries, the project execution was similar along the main dimensions except the use of the PEM and the utilisation of the 3D design environment and the BIM, respectively, which makes it more relevant to generalise on the results.

In the paper, conceptual generalisation (Tjora, 2012) is initially adopted as a way of generalizing in qualitative research in general and case study research in particular. In addition, the aim is to fulfil several requirements in moderatum generalisation (Payne & Williams, 2005) in order to have a broader foundation for generalisation. The study is limited to the subtypes of the focal phenomenon and the focus is on the current conditions through the ongoing projects. All this corresponds with "social structures", which has a high ontological status.

So can we generalise the findings on the oil and gas industry to the construction industry? The working hypothesis still is that the more similar the project execution characteristics of the two industries with the variables inherent in the PEM, the 3D design environment/the BIM are, the more likely a possibility is to generalise and transfer findings between these project-based industries. So far, many similarities have been detected. The PEM is based on codified knowledge about project execution, which makes it more transferable to other organisations and across certain industries. Principally, the use of the 3D design environment versus the BIM is similar, except on model complexity and object information. Thus, it is herein argued that these necessary similarities create a basis for generalisation of findings on project execution between the two industries.

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# A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects

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**A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects**

# Abstract

**Purpose** - Traditionally, progress in detail engineering in construction projects is reported based on estimates and manual input from the disciplines in the engineering team. Reporting progress on activities in an engineering schedule manually, based on subjective evaluations, is time consuming and can reduce accuracy, especially in larger and multidisciplinary projects. How can progress in detail engineering be reported using BIM, and connected to activities in an engineering schedule? This paper introduces a three-step process for reporting progress in detail engineering using building information modeling (BIM), to minimize manual reporting and increase quality and accuracy.

**Design/methodology/approach** - Findings are based on studies of experiences from execution of projects in the oil and gas industry. Data are collected from an engineering, procurement and construction (EPC) contractor and two engineering contractors, using case study research.

**Findings** - In the first step, control objects in building information models are introduced. Statuses are added to control objects, to fulfill defined quality levels related to milestones. In the second step, the control objects with statuses are used to report visual progress and aggregated in an overall progress report. In the third step, overall progress from building information models are connected to activities in an engineering schedule.

**Originality/value** - Existing research related to monitoring and reporting progress using BIM focus on construction and not detail engineering. The research demonstrates that actual progress in detail engineering can be visualized and reported through the use of BIM and extracted to activities in an engineering schedule, through a three-step process.

**Keywords:** BIM, control object, engineering schedule, LOD, object status, progress management, project execution model

## Introduction

The main focus in research on reporting progress with the use of BIM in the construction industry is related to construction and the 4D concept, where objects are linked to a construction schedule, and time represents the fourth dimension. BIM can be viewed as "a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model" (Azhar *et al.*, 2012, p. 17). Traditionally, a 3D model and a construction schedule, which have been developed separately, have been combined into a 4D model. A schedule simulation is utilized to link the objects with the related scheduling activities, to visualize progress in construction. The resulting 4D model displays the construction sequence by showing consecutive objects as a progression over the time-span of the construction process (Wang *et al.*, 2014). The 4D concept has been adopted by the construction industry (Hartmann *et al.*, 2012) and several commercial software are available for 4D construction planning (Sacks *et al.*, 2009). Later BIM developments, such as the use of RFID/laser tagging and augmented reality (Golparvar-Fard *et al.*, 2012; Matthews *et al.*, 2015), and time-lapse images and laser scanning (Han and Golparvar-Fard, 2017), have been introduced for planning and following up construction. When it comes to progress management, Kim *et al.* (2013a) proposed a method for measuring construction progress based on the use of as-planned data from the BIM and 3D as-built data obtained on the building site via remote-sensing technology. Matthews *et al.* (2015) examined how a cloud-based BIM software could be used during construction to provide real time progress monitoring and improve decision making. Bosché *et al.* (2015) presented a method for progress tracking of MEP components with an automated comparison of as-built and as-planned, through as-built laser scans and as-designed BIM models. Previous research has also indicated that it is possible to report progress by generating activities in a schedule based on BIM. Kim *et al.* (2013b) generated a simplified construction schedule using BIM with a limited number of basic building components, by creating construction tasks, calculate activity durations using productivity rates and applying sequencing rules. Common for these and similar research on progress management is the primary focus on construction, and not detail engineering. When it comes to detail engineering, there is also a need for enhanced interoperability between BIM and scheduling software (Kim *et al.*, 2013b).

In large projects in the oil and gas industry, there has over the years been an increased utilization of a 3D design environment, which is a multidiscipline and object-based 3D design (Kvaerner, 2012a). This corresponds to building information modeling (BIM) in the construction industry. A Norwegian engineering, procurement and construction (EPC) contractor (hereinafter called EPC contractor), and a Norwegian engineering contractor (hereinafter called engineering contractor 1) early started focusing on how they could report progress in detail engineering and not only construction. This was

based on their experience with visualizing and simulating progress in construction using a 3D design environment (hereinafter called BIM).They started to set statuses on objects that had reached a certain level of quality in the 3D models, corresponding to building information models in the construction industry. A building information model can be defined as an "accurate virtual model of a building constructed digitally [that] when completed […] contains precise geometry and relevant data needed to […] realize the building" (Eastman *et al.*, 2008, p. 1). The reason was to try to move away from estimates, sometimes guesstimates, on how far each discipline had come, when reporting progress towards an engineering schedule. When a discipline had completed a defined work, the objects were given relevant statuses. Eventually the EPC contractor could extract statuses directly from the 3D models (hereinafter called building information models), which formed the basis for extracting progress from the building information models in detail engineering and the subsequent connection towards an engineering schedule.

The research question asked in this paper is: How can progress in detail engineering be reported using BIM, and connected to activities in an engineering schedule? The focus of this paper is to assess how BIM can be used to report progress in detail engineering and connect to activities in an engineering schedule through a three-step process, based on studies of experiences from projects in the oil and gas industry. The first step introduces the necessary preparations for reporting progress from building information models, as defined in a project execution model (PEM). A PEM defines a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones (Kvaerner, 2012b). The second step focuses on how progress data from building information models can be used to report visual and overall progress. The third step focuses on how reported overall progress can be connected to activities in an engineering schedule. As a background, this paper describes how BIM is used, introduces the principles of the PEM in relation to knowledge management, and compares the stages in detail engineering between the two industries. The key activities in the three-step process and applicability towards the construction industry are outlined in the discussion. In the conclusion, key contributions and suggestions for further research are identified. All project related data in this paper have been anonymized as the real data made available to the research is commercially sensitive.

# Background

## BIM

BIM is an acronym for both building information modeling, as a process, and building information model, as a virtual model. Numerous research articles identify existing and potential utilization of BIM.

Among those relevant as a backdrop for this research, Sacks *et al.* (2010a) identifies BIM functionality, Azhar (2011) pinpoints BIM applications and benefits, and Bryde *et al.* (2013) identifies benefits of BIM towards project management. Another term that is used in parallel with BIM in the construction industry is Virtual Design and Construction (VDC), which is "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives" (Kunz and Fischer, 2012, p. 1). VDC extends the scope of BIM, and does not only include the product, which is typically a facility or the components and systems of the building, but also organization and work processes (Fischer *et al.*, 2017). This paper emphasize the interplay between product and process, through the focus on BIM and PEM.

The structure and use of BIM in the two industries is somewhat different. The size and model complexity, and thereby the amount of information related to the modeling objects, are in general greater in the oil and gas industry than in the construction industry. This has resulted in many connected support systems that works as external databases, in order to be able to process the large amount of information in the BIM software. The modeling objects therefore contain less information, because most of the information are defined in the corresponding support systems – connected to the modeling objects with unique tag numbers. In the construction industry, on the other hand, relevant information is contained within each modeling object in the building information model. The exchange of building information models within and between disciplines, and between different BIM-based software, is in the oil and gas industry based on proprietary formats. In contrast, the construction industry uses open standardized formats, such as Industry Foundation Classes (IFC) (BuildingSMART, 2017), which increases interoperability.

## Project execution model

The construction industry is a knowledge-intensive and experience-based industry (Yang *et al.*, 2013). With the rapid BIM adoption, the industry is undergoing transition to a new era of digital information. Still, the dominant form of knowledge on project execution still exists in the form of tacit knowledge (Nepal and Staub-French, 2016). Knowledge gained by a project team during a project is often not retained and used on future projects. A crucial step for counteracting this is the conversion of tacit knowledge to explicit knowledge, where only explicit knowledge can be integrated in an organizational knowledge base. This transformation can be supported by knowledge management (Lindner and Wald, 2011). Knowledge management can be defined as "the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage" (Carrillo and Chinowsky, 2006, p. 2), and is critical for process improvement. When implementing knowledge management, there can be several barriers, such as lack of standard

processes, poor organizational culture, insufficient funding, employee resistance and poor IT infrastructure (Yang *et al.*, 2013). According to Carrillo and Chinowsky (2006), knowledge management systems can be implemented to facilitate the capture, access, and reuse of information and knowledge. Effective knowledge management systems have the ability to communicate and preserve knowledge across all stages of a construction project (Deshpande *et al.*, 2014). The dominant type of knowledge management system that has been used in practice, is what Newell (2015) calls repository system, which is based on facilitating the sharing of explicit knowledge. To succeed, the repository must contain knowledge useful for employees looking for answers and solutions in execution of projects. The repository must not only contain useful knowledge but the knowledge must be intuitive and easy to find.

Developing knowledge management systems requires considerable costs and human-resource efforts (Yang *et al.*, 2013; Lindner and Wald, 2011) There have been several examples of knowledge management systems developed for the construction industry, where only a few of these are related to the use of BIM. BIM can be utilized as an efficient tool for visualizing construction progress. A BIM-based knowledge management system was developed by Lin (2014), enabling engineers to share and reuse their knowledge and experience during construction. Knowledge information were stored using BIM, through attributes in modeling objects. Deshpande *et al.* (2014) created a BIM-based knowledge management system, where important knowledge from lessons learned during engineering and construction were stored using BIM, through attributes in the modeling objects. The knowledge generated could then be published and used in other BIM projects. These and other similar systems are platforms for knowledge sharing in construction projects. They are solutions to share best practice using BIM. Despite this, none of these systems have adapted the information and transformed that to a methodology for executing construction projects.

A PEM is based on the principles of knowledge management, and assist the project team to execute and complete activities at the right time and in the right sequence. The objective is to secure predictability in project execution using a standard methodology well known to the project team (Kvaerner, 2012b). A PEM is not a model per se, but a methodology used in all projects, and is the documented experience for how to execute and deliver projects (AkerSolutions, 2014b).

The PEM, as developed by the EPC contractor and engineering contractor 1, is used as a basis for this research. It is based on the knowledge areas in PMBOK (PMI, 2013), especially the Project Integration Management knowledge area, with focus on actions that are crucial to a controlled project execution. The PEM is structured as a three-level pyramid, to clearly define the methodology, simplify navigation and ensure consistency, with a strategic level on top, followed by a control level and execution level

(see Figure 1). The strategic level describes the life cycle of a project, split into phases with requirements for each phase. All phases are divided into multidiscipline stages, and the control level describes the stages to each of the phases, where each stage is ending up in a milestone. This is similar to the principles of a stage-gate process (Cooper, 1990). Objectives and focus areas for each stage and milestone requirements are also defined. The strategic and control level are more general and should be used in all projects. What differentiates the PEM compared to other knowledge management systems and stage-gate models is the execution level. The execution level describes all work processes and activities to management and execution disciplines. This level is much more comprehensive than the first two. The extent of use will depend on the type, size and complexity of the project (Kvaerner, 2012b).
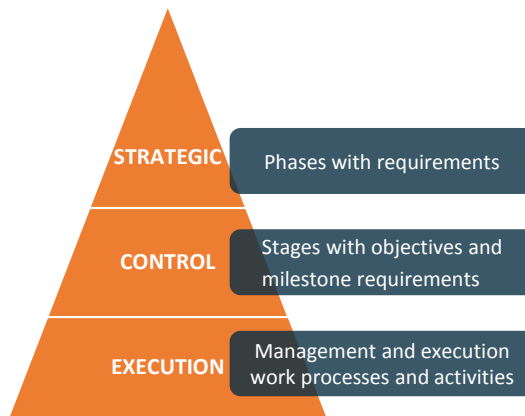


*Figure 1: The three levels of the PEM. Adapted from Kvaerner (2012b)*

The combination of PEM and BIM has not been selected randomly. The first two levels of a PEM can be used without BIM, and BIM can be used without a PEM. However, to fully exploit the possibilities with the PEM requires the use of BIM, especially on the execution level, and the use of a PEM will streamline and further enhance the use of BIM.

To increase transferability of the findings towards the construction industry, the stages of detail engineering should be based on the same key objectives in both industries. The control level in the PEM describes the stages to each of the project phases (Kvaerner, 2012b). Using the PEM as a benchmark (AkerSolutions, 2014b), the stages in detail engineering have been compared with standards and industry norm initiatives in the construction industry, through the "life-cycle stages" in ISO 29481-1 (ISO, 2010) and the RIBA Plan of Work (RIBA, 2013) (see Figure 2). The more similar the stages and milestones are, the more relevant the principles in the PEM are towards the construction industry.
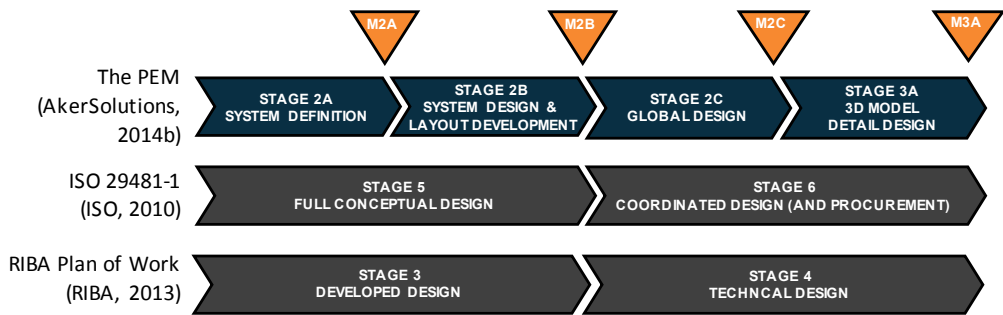
M2A    M2B    M2C    M3A

The PEM (AkerSolutions, 2014b)

| STAGE 2A SYSTEM DEFINITION | STAGE 2B SYSTEM DESIGN & LAYOUT DEVELOPMENT | STAGE 2C GLOBAL DESIGN | STAGE 3A 3D MODEL DETAIL DESIGN |

ISO 29481-1 (ISO, 2010)

| STAGE 5 FULL CONCEPTUAL DESIGN | STAGE 6 COORDINATED DESIGN (AND PROCUREMENT) |

RIBA Plan of Work (RIBA, 2013)

| STAGE 3 DEVELOPED DESIGN | STAGE 4 TECHNICAL DESIGN |

*Figure 2: Stages of detail engineering in the PEM, compared to the construction industry*

The principle is that the output at the end of each stage are defined through milestones or stage gates, and must be verified through stage gate reviews, to continue as input to the next stage. This conversion is similar to a project management process, where the result or output of a process becomes the input of the subsequent process (PMI, 2013). A milestone or stage gate is comparable to what Schade *et al.* (2011) identifies as a quality gate, where design maturity is coordinated and evaluated. The stages and milestones in detail engineering, as defined in the control level in the PEM, start at stage 2A ("System definition"), with corresponding milestone M2A, where the concept design is confirmed and optimized. At stage 2B ("System design & layout development"), with milestone M2B, the main layout and structures are confirmed, and the detail engineering premises are completed. These first two stages correspond to the "Full conceptual design" stage outlined in ISO 29481-1 and the "Developed design" stage outlined in the RIBA Plan of Work, where the concept design is developed and the discipline designs are progressed until spatial coordination has been completed. When milestone M2C ("Global design complete"), is reached, the designs shall be clash free and complete, except for final detailing. At the last stage, 3A ("3D model detail design"), with milestone M3A, all disciplines have completed their designs to a level ready for fabrication. These last two stages correspond to the "Coordinated design (and procurement)" stage in ISO 29481-1 and the "Technical design" stage in RIBA Plan of Work, where the discipline designs are further refined to provide technical definition of the project. To summarize, the first two and last two stages of detail engineering in the PEM have similar key objectives to each of the corresponding two stages of ISO 29481-1 and RIBA Plan of Work, which increases the relevance and transferability to the construction industry.

## Research method

The research is qualitative, conducted as case study research (Yin, 2009). Data are collected from three case projects in the oil and gas industry, through the EPC contractor, engineering contractor 1 and an American engineering contractor (hereinafter called engineering contractor 2). The case projects are

delivery of topsides of production platforms on the Norwegian continental shelf, executed as EPC contracts, which are comparable to design-build contracts in the construction industry. Topsides holds the facilities to process oil and gas from the reservoir in the seabed below, and have been designed and built for installation on steel jackets. The primary case used in the research is the topside for one of four Johan Sverdrup platforms, consisting of living quarters and utility module, which started detail engineering in 2015 (Kvaerner, 2015b). It is executed as a joint venture between the EPC contractor and engineering contractor 2 as engineering and procurement contractor. The secondary cases support the research and findings on the use of a PEM and BIM. These are the topsides for the Eldfisk and Edvard Grieg platforms, mainly consisting of living quarters and utility modules. They were completed in April 2014 (Kvaerner, 2014) and April 2015 (Kvaerner, 2015a), respectively. Both were executed with the EPC contractor as a main contractor and engineering contractor 1 as engineering and procurement subcontractor. The selection of case projects and access to these were given by the EPC contractor, based on the information they could contribute with on the use of the PEM and utilization of BIM. Empirical data have been collected through interviews. These were supplemented with company and project documentation, not only to get access to relevant data, but also to corroborate the data collected through interviews and to acquire additional information necessary for full understanding (Yin, 2009). The goal was to go in-depth on how BIM was used to report progress in detail engineering and how progress data could be connected to an engineering schedule.

16 semi-structured interviews with informants in key positions have been carried out, with the use of interview guides, from February 2013 to June 2016 (see Table 1). This includes 10 with the EPC contractor, three with engineering contractor 1 and three with engineering contractor 2. The interview guides comprised questions related to the topics to be covered in each interview. The questions were often sent to the interviewee in advance, so that they could have time to prepare. The questions were not always asked in the exact order outlined in the interview guide, and were often modified, based on the flow of each interview, with additional unplanned questions asked to follow up on what the interviewee had said. The goal was to get the interviewees to reflect on their own experiences and opinions related to the topics. The average length of the interviews has been 1 hour 47 minutes. Each interview has been conducted with one to three interviewees in key positions.

| Interview date | Interview duration | Inteview source | Interviewee 1 role | Interviewee 2 role | Interviewee 3 role |
|---|---|---|---|---|---|
| 130215 | 02:22 | EPC contractor | *Information Manager* | *Information Manager* | |
| 130311 | 01:55 | EPC contractor | *Information Manager* | *Project Manager* | |
| 130419 | 01:10 | EPC contractor | *Information Manager* | | |
| 130808 | 02:04 | EPC contractor | *Information Manager* | | |
| 131126 | 02:29 | EPC contractor | *Information Manager* | *Discipline Lead* | |
| 131126 | 01:20 | EPC contractor | *Information Manager* | *PEM Manager* | |
| 140314 | 02:00 | EPC contractor | *Project Manager* | | |
| 141218 | 03:12 | EPC contractor | *Project Manager* | | |
| 150511 | 01:31 | EPC contractor | *Project Manager* | | |
| 160617 | 01:37 | Engineering contractor 1 | *Engineering Manager* | *Engineering Manager* | |
| 160620 | 01:25 | Engineering contractor 2 | *Engineering Manager* | | |
| 160620 | 01:27 | Engineering contractor 2 | *Information Manager* | *CAD Manager* | *Data Manager* |
| 160621 | 00:39 | Engineering contractor 2 | *Procurement Planning* | | |
| 160621 | 01:01 | EPC contractor | *Integration Manager* | | |
| 160624 | 02:27 | Engineering contractor 1 | *PEM Manager* | | |
| 160627 | 01:54 | Engineering contractor 1 | *PEM Manager* | *Planning Manager* | |
| **16** | **28:33** | **TOTAL** | | | |
| | **01:47** | **AVERAGE** | | | |

*Table 1: Overview of interviews conducted as part of data collection*

The stepwise-deductive-inductive (SDI) method (Tjora, 2012) has been applied to analyze the collected data. The principle of this method is to work in a series of steps from data to concepts or theories (inductive) and then go back to the data to empirically verify those concepts or theories (deductive). The collected data has been transcribed and "empiric-close" coding, that reflects the contents of the text, has been developed. This is what Kvale (2009) calls "data-driven" coding, where no codes have been defined in advance, but are developed through the analysis of the collected data. The codes have been sorted into larger groups of themes, called categories. These are used as to develop concepts that capture central characteristics of observations, as a basis for the findings in the paper. Data analysis has been supported using computer-assisted qualitative data analysis software (CAQDAS).

# Report progress in detail engineering using BIM

Using BIM to report progress in detail engineering, as presented in this paper, is a three-step process. Based on the findings from the case projects, a flowchart has been developed to highlight the main activities in each step (see Figure 3). In the first step, the prerequisites and preparations for reporting progress using BIM are presented. In the second step, progress data from BIM are used to report both visual and overall progress. In the third step, the engineering schedule is prepared and progress on activities are reported based on BIM.
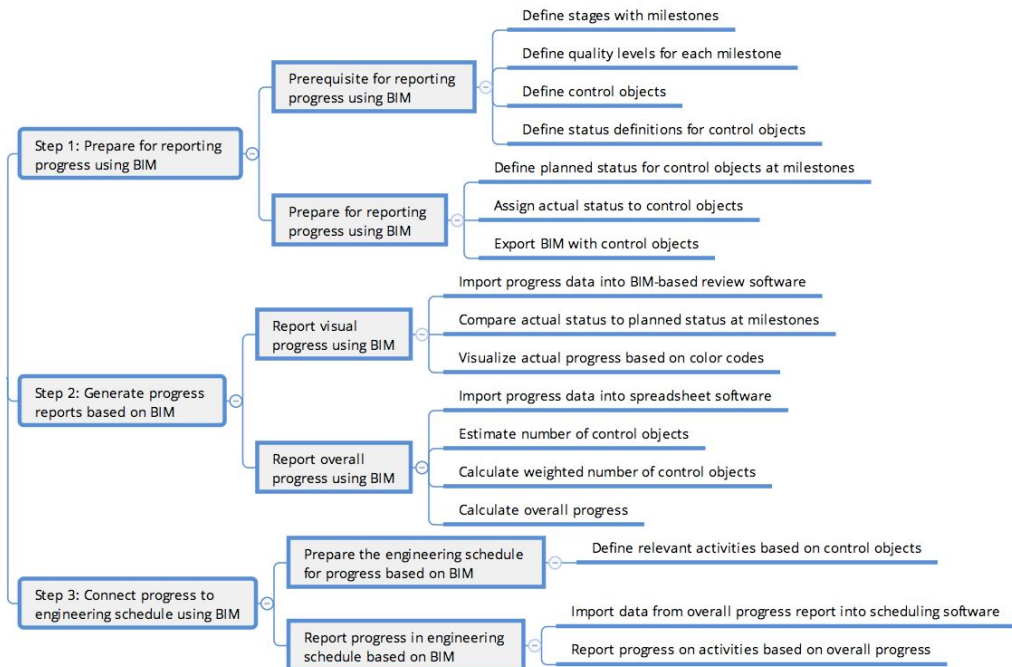
*Figure 3: Using BIM to report progress in detail engineering in three steps*

## Step 1: Prepare for reporting progress using BIM

### Prerequisite for reporting progress using BIM

Research on the case projects indicate that a prerequisite for reporting progress using BIM is the use of principles defined in the execution level of the PEM, as developed by the EPC contractor and engineering contractor 1. There are three important principles that should be adapted. The first principle is that the building information models should achieve a higher quality level at each milestone in detail engineering. In the execution level of the PEM, a quality level description is defined for each discipline. An extract and simplified version of this is illustrated with the structural discipline (see Table 2). Here, quality level 1 (QL1) will be achieved at the M2A milestone, quality level 2 (QL2) at the M2B milestone, quality level 3 (QL3) at the M2C milestone, and quality level 4 (QL4) at the M3A milestone (AkerSolutions, 2014b) in detail engineering.

| QUALITY LEVEL DESRCIPTIONS | | | | | | |
|---|---|---|---|---|---|---|
| Key deliverable: | | | STAGE 2A | STAGE 2B | STAGE 2C | STAGE 3A |
| **3D MODEL** | | | **QL1** (M2A) | **QL2** (M2B) | **QL3** (M2C) | **QL4** (M3A) |
| CTR No.: | STRUCTURAL Group of Control Object (GCO) | Check List | | | | |
| 0082 | **Main Structure (MS):** | | | | | |
| 0082 | Trusses | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Main support nodes | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Web framings | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Shells | 3D Model Structural | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". | |
| 0082 | Bulkheads | 3D Model Structural | S1; "Preliminary". | S2; "Released for verification / IDC". | S3; "Frozen Interface". | S4; "Detail Design Completed". |
| 0085 | **Secondary Structure (SS):** | | | | | |
| 0086 | **Outfitting Structures (OS):** | | | | | |
| 0087 | **Small Item Structures (SIS):** | | | | | |
| 0088 | **Temporary Structures (TS):** | | | | | |

*Table 2: Control objects in the PEM with statuses for each quality level (AkerSolutions, 2013b)*

The second principle is that the building information models should be split in control objects. Unlike a modeling object in a building information model, a control object consists of several modeling objects of the same type, or modeling objects that are grouped together with other types of modeling objects. A truss is an example of a control object, where the truss itself consists of several modeling objects, such as beams, columns, stay cables etc. Control objects are developed to better adapt to fabrication and a desired construction sequence. The idea is to have a higher abstraction level more related to actual deliverables, and thereby reduce the number of objects and object types to coordinate for each discipline. In the quality level description in the PEM (see Table 2), a selection of control objects for the structural discipline are identified and grouped.

The third principle is that the degree of completion each control object should have to achieve a certain quality level at each milestone, are defined through status requirements. It is possible to get control of the engineering deliverables using statuses that defines quality and maturity of the control objects in the building information models. The status definitions, which in the PEM consist of a status code, name and description, are common for all control objects and all disciplines (AkerSolutions, 2013). According to the PEM, there are four main statuses on control objects in building information models in detail engineering (see Figure 4). The statuses define the grade of completeness for a control object at the various milestones. To illustrate this, a small red circle can symbolize the degree of accuracy around the placement on the surrounding circle. The first is status S1, where the control object still

has a preliminary location. The next is status S2, where the shape and location is set for interdisciplinary design control (IDC). The next is status S3, where the location of the control object and interface to other disciplines are frozen. This is a critical status for all control objects. When frozen, the shape and location of control objects in a building information model, and all interfaces towards other control objects should, by definition, not be changed. The last is status S4, where the final detailing of the control objects are finished and deliverables are ready to be issued for construction (IFC) (AkerSolutions, 2013).
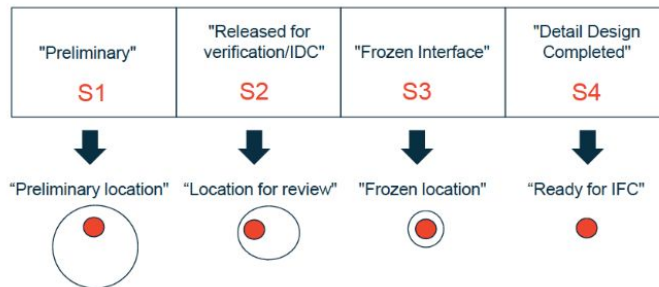


*Figure 4: Object placement related to status definitions (AkerSolutions, 2014a)*

By following the three principles through defining control objects for each discipline and setting statuses on these to reach a desired quality level each milestone, it is possible to compare and follow up planned progress with actual progress based on BIM.

## Prepare for reporting progress using BIM

Status must be set on all control objects in the building information model to each discipline, which enables control of the engineering progress. Introducing control objects also makes it more manageable for each discipline to set the right statuses on their design. The quality levels at each milestone describe maturity requirements for control objects in a building information model, from creation to completion. Each discipline must therefore define the status that must be achieved for their control objects to reach the quality levels at each milestone in detail engineering. This is illustrated in Table 2, with control objects to the "main structure" control object group for the structural discipline. Certain control objects have a higher status to be achieved at a milestone than others, because these are prerequisites for other control objects, and must therefore have reached a higher maturity and quality at the milestone. When all control objects have defined a planned status at each milestone, the actual status can be set. Status are set on all control objects directly in the BIM software by each discipline. Status should be set on the attributes in the associated modeling objects, and updated when a higher status is achieved.

Progress data can be extracted from building information models by exporting relevant attributes from control objects through the associated modeling objects. Besides control object name and status, the attributes relevant for progress reports includes location and belonging control object group. Being able to set relevant attributes on modeling objects in the building information models, especially which control object the modeling object belongs to and what status the control object has, is mandatory to be able to aggregate and export necessary information on progress.

## Step 2: Generate progress report based on BIM

### Report visual progress using BIM

Building information models with statuses on control objects can easily be imported into a BIM-based review software, such as Autodesk Navisworks (Autodesk, 2016) which handles both proprietary and open formats (IFC), or Solibri Model Checker (Solibri, 2016), which is based on open formats (IFC). Here, model views and reports based on statuses can be defined. With the actual status defined on each control objects, through the associated modeling objects, status reports that illustrates which status each control object has can easily be aggregated. This includes the number of control objects for each control object group and discipline. Any missing control objects, or statuses that has not been set or is missing, can be identified. Actual status can now be compared to planned status in the BIM-based review software. When actual status for each control object has been set, the actual progress can be reported, by comparing the planned status with the actual status at the milestones. At each milestone in detail engineering the actual status on each control object must be equal to the planned status, to achieve the desired quality level. This can be aggregated and displayed in a report in the BIM-based review software, with both planned and actual status for each milestone. Any deviation between planned and actual status can then easily be identified.

By assigning a color code to each status, the control objects in the building information models can visualize the quality and maturity directly, and support the disciplines in identifying what is still being developed and what is frozen. According to Sacks *et al.* (2009) visualization of process status is needed and should be displayed in a manner that can be readily understood by all, regardless of their technical knowledge. Building information models with color coding, used as an added feature of multidiscipline design reviews, is very useful for seeing statuses on the control objects and coordinating where the disciplines are and what is missing. Similarly, Sacks *et al.* (2010b) defined the state of readiness of a work package or a task, measured through maturity. The maturity index was displayed using color-coded symbols on task icons. Chen and Luo (2014), described how the building information models could visualize quality status in construction with different color codes, grouped in two; before or after

inspection was performed. Common for these and similar research is that the primary focus is on construction, and not detail engineering.

The color coding displayed in Table 3 is from the Johan Sverdrup case project, and is much like a traffic light – red to green, with red being status S0, when the control object is defined, yellow being status S4, when the detail design is completed, and green being status S5, when issued for construction. Blue is status S3, and illustrates when the control object is frozen.

| ENGINEERING STATUS DEFINITIONS | | | | | | |
|---|---|---|---|---|---|---|
| **STATUS** | S0 | S1 | S2 | S3 | S4 | S5 |
| **NAME** | Defined | Preliminary | Released for verification/ IDC | Frozen interface | Detail design completed | Issued for construction |

*Table 3: Status definitions for control objects with color coding. Adapted from AkerSolutions (2013); K2JV (2015)*

A color coded view of the building information model can be displayed. This can be used as a direct basis for reporting progress. In the case project, color coded versions of building information models were used actively by the engineering team, and issued to the client on a regularly basis. This is illustrated (see Figure 5) with an extract from one of the decks for the structural disciple (K2JV, 2015).
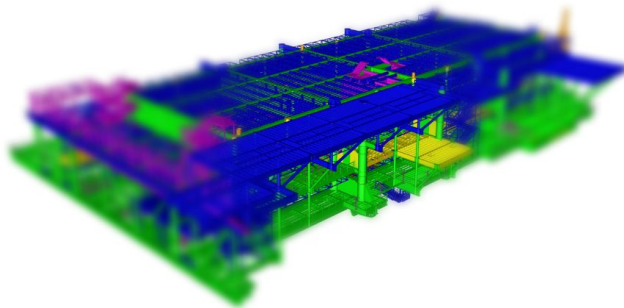


*Figure 5: Extract of a color coded version of a building information model for the structural discipline (K2JV, 2016a)*

## Report overall progress using BIM

Status is both quality and quantity. This can be illustrated using the truss in step 1 as example. If the structural discipline has achieved status S4 at quality level 3 (QL3) at milestone M2C for their trusses (see Table 2), these control objects have a quality that in this example enables the discipline to start deliveries and extract information for construction. At the same time, the achieved quality level is based on quantity, because there will be a given number of trusses with status S4. If not all these control objects are on status S4, the structural discipline is behind schedule. If all trusses have status S4, the discipline is on schedule, and satisfy both quality and quantity.

In the beginning of a project, each discipline should spend time to establish where they are going, to be able to plan and measure progress. This requires a realistic number of control objects to be evaluated, i.e. number of modelled and estimate of unmodeled control objects. The report is only as good as the information contained within the building information models. Every discipline must therefore ensure that every control object has the right status assigned to it. The estimated number of each control object must be set at the start of detail engineering. If similar projects have been executed earlier, the disciplines should be able to estimate the number of control objects quite well based on experience. If no similar projects have been executed earlier, which is more common in the construction industry, the estimation must be based on the knowledge each discipline have about the specific project. Each control object consists of several modeling objects, which gives a considerable lower number of control objects than modeling objects for each discipline. The fact that control objects also have a higher abstraction level than modeling objects, makes the estimation more precise and manageable.

Progress reports based on progress data from the BIM software are developed in order to present the quality and maturity of the design. Actual status on control objects for each discipline can be imported into a spreadsheet software to calculate actual progress. In the Johan Sverdrup case project, an overall progress report, where the overall progress for a discipline is calculated, has been created. The report is based on the number of control objects and statuses on these. This is illustrated using an extract from the structural discipline as example (see Table 4). The overall progress report is based on attribute information from the modeling objects to each control object in the building information model, exported from the BIM software, in this case PDMS. It is an aggregation of the number of control objects and their statuses within each control object group for each floor (level). Based on these numbers, the overall percentage complete can be calculated for each control object group. In the overall progress report, the control objects are grouped together in control object groups ("OE class") for each level, for the purpose of reporting. The control object groups are agreed upon within the disciplines, as to how they are going to split up their work. Each of these can be independently tracked for progress. The estimated ("Est.") and actual ("Act.") number of control objects within each control object group are displayed. The number of control objects for each control object group ("OE report stage") with status S0 ("0") to status S5 ("5") are summarized.

| | | COUNTS | | OE REPORT STAGE | | | | | | OVERALL % COMPLETE |
|---|---|---|---|---|---|---|---|---|---|---|
| AREA | OE CLASS | EST. | ACT. | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total LEVEL 1 | | | | | | | | | | |
| LEVEL 1 | MainStruct | 99 | 96 | 0 | 0 | 0 | 0 | 0 | 96 | 97 % |
| LEVEL 1 | Not MainStruct | 464 | 494 | 42 | 15 | 119 | 50 | 11 | 256 | 69 % |
| LEVEL 1 | SecStruct | 22 | 22 | 0 | 0 | 0 | 0 | 0 | 22 | 100 % |
| LEVEL 1 | OutfittingStruct | 152 | 158 | 2 | 8 | 10 | 31 | 3 | 102 | 81 % |
| LEVEL 1 | SmallItemStruct | 285 | 309 | 39 | 6 | 108 | 18 | 7 | 125 | 60 % |
| LEVEL 1 | TempStruct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 % |
| Total LEVEL 2 | | | | | | | | | | |
| Total LEVEL 3 | | | | | | | | | | |
| Total for K2JV Scope (Levels 1, 2, 3) | | | | | | | | | | |

*Table 4: Extract from overall progress report for the structural discipline (KBR, 2016)*

At a given cut-off date, there is a certain distribution of control objects with different statuses (S0-S5) within each control object group for each level. There is also estimated and actual number of control objects for each control object group, for each level. With these numbers in place, the overall percentage complete for each control object group, for each level, can be calculated. For the calculation to be more accurate, the status on each control object for each discipline should be weighted to correspond to a given degree of completeness. In the Johan Sverdrup case project, each main discipline has developed a table that illustrates the stages of development for each status (see Table 5). For every status, there is a % complete figure along with the associated statuses S0 ("OE 0") to S5 ("OE 5"). The percentages in the table are for the structural discipline. Each discipline has got slightly different weighting. The percentages are based on best practice from previous projects, and are used as a basis for calculations in the report. The figures are not far from a 0%-20%-40%-60%-80%-100% distribution of completeness for status S0-S5, which could be a reasonable starting point for projects in the construction industry.

| | All Steel |
|---|---|
| OE 0 | 5% |
| OE 1 | 20% |
| OE 2 | 35% |
| OE 3 | 60% |
| OE 4 | 80% |
| OE 5 | 100% |

*Table 5: Table of % complete for each status for the structural discipline (K2JV, 2016c)*

The overall progress, or more specifically the overall percentage complete for each control object group, is calculated based on the estimated or actual number of control objects, and the weighted

number of control objects for each status. To illustrate this, the calculation for the main structure, secondary structure and outfitting structure control object groups are displayed (see Table 6), for a given cut-off date. The overall percentage complete for these control object groups are calculated to be 97%, 100% and 81%, respectively (see yellow marking in Table 6).

| AREA | OE CLASS | COUNTS | | OE REPORT STAGE | | | | | | OVERALL % COMPLETE |
|---|---|---|---|---|---|---|---|---|---|---|
| | | EST. | ACT. | 0 | 1 | 2 | 3 | 4 | 5 | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| LEVEL 1 | MainStruct | 99 | 96 | 0 | 0 | 0 | 0 | 0 | 96 | 97 % |
| | | | | | | | | | | |
| LEVEL 1 | SecStruct | 22 | 22 | 0 | 0 | 0 | 0 | 0 | 22 | 100 % |
| | | | | | | | | | | |
| LEVEL 1 | OutfittingStruct | 152 | 158 | 2 | 8 | 10 | 31 | 3 | 102 | 81 % |

| OE REPORT STAGE | | | | | | OVERALL % |
|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | |
| | | | | | | |
| 5 % | 20 % | 35 % | 60 % | 80 % | 100 % | |
| 0 | 0 | 0 | 0 | 0 | 96 | 97 % |
| 5 % | 20 % | 35 % | 60 % | 80 % | 100 % | |
| 0 | 0 | 0 | 0 | 0 | 22 | 100 % |
| 5 % | 20 % | 35 % | 60 % | 80 % | 100 % | |
| 0,1 | 1,6 | 3,5 | 18,6 | 2,4 | 102 | 81 % |

*Table 6: Extract from overall progress report with calculations for the structural discipline (KBR, 2016)*

The calculation is a two-step process. First, the number of control objects for status S0 ("0") to S5 ("5") within each control object group is weighted with the % complete figure. This gives an updated distribution of control objects for each status. Second, the weighted number of control objects for each status are summarized and divided on the highest of the estimated or actual number of control objects to get the overall percentage complete. Similar calculations are done for all control object groups. Using the outfitting structure control object group as example (see Table 6), the first step summarizes the number of control objects for each status with the % complete figure for the corresponding status. This gives the following weighted numbers of control objects for status S0 to S5: 0.1 (2*0.05), 1.6 (8*0.2), 3.5 (10*0.35), 18.6 (31*0.6), 2.4 (3*0.8) and 102 (102*1). In the second step, the sum of the weighted numbers of control objects for each status are divided with the highest number of the estimated or actual number of control objects. This gives an overall percentage complete of 81% ((0.1 + 1.6 + 3.5 + 18.6 + 2.4 + 102)/158).

## Step 3: Connect progress to engineering schedule using BIM

### Prepare the engineering schedule for progress based on BIM

A prerequisite for connecting progress based on BIM to an engineering schedule is that the schedule consists of activities that can be related to progress data from the building information models, either indirectly or directly. Indirectly, activities can be defined in a way so that building information models can be used as input to the disciplines, often in addition to drawings and other documentation, when reporting progress. This is the more traditional approach in projects where BIM is used. Directly, activities can be defined in a way so that progress data extracted from the building information models can be used as direct input, when reporting progress.

The engineering schedule for detail engineering from the Johan Sverdrup case project is broken down in different disciplines and levels. For the BIM deliverables, the activities for each level are related directly to control object groups, which also correspond to the overall progress report. These are displayed with the combination of level and control object group. For the structural discipline, the activities for the lowest level are:

"Cellar Deck Main Steel 3D PDMS Modelling Updates"
"Cellar Deck Secondary Steel 3D PDMS Modelling Updates"
"Cellar Deck Outfitting Steel 3D PDMS Modelling Updates"

## Report progress in engineering schedule based on BIM

To be able to report progress based on BIM in the engineering schedule, progress data must be imported into a scheduling software and linked to relevant activities. The engineering schedule for detail engineering, developed at the Johan Sverdrup case project, is broken down in topside modules, disciplines and decks (levels). It is an aggregation of schedule activities for deliverables, mainly related to BIM. This is illustrated in an extract from the engineering schedule for the structural discipline, from Primavera (Oracle, 2016), which is their scheduling software (see Figure 6). Progress is reported on the activities through progress on the control object groups. The closer to issuing deliverables for construction, the more complete and objective the information from the building information models will be. Progress on activities that are related to control object groups, as defined in the overall progress report, are reported directly from the building information models. The link from the building information models to the planning tool is done through the overall progress report. The extract from the schedule for the structural discipline, illustrates the BIM deliverables for the first level ("cellar deck"). Each activity is related to the overall percentage complete from the overall progress report. The actual progress for the activities ("3D PDMS Modelling") through the control object groups main steel, secondary steel and outfitting steel is 97% complete, 81% complete and 100% complete, respectively (see yellow marking in Figure 6). These are the same numbers as in the overall progress
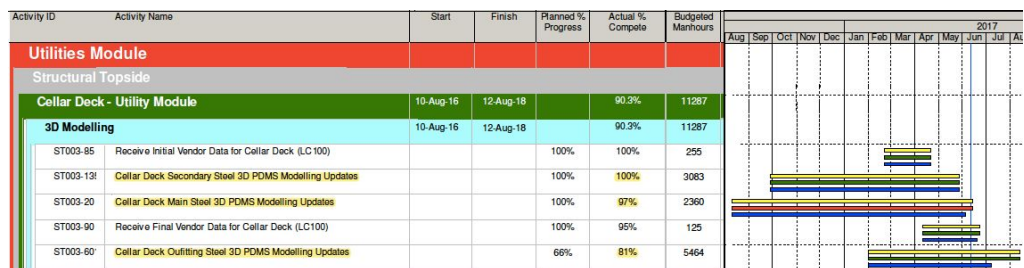


*Figure 6: Extract from an engineering schedule for the structural discipline (K2JV, 2016b)*

report (see Table 6). It illustrates that progress can be extracted from the building information model through statuses on control objects for each control object group, and used as input to report progress on activities in detail engineering in an engineering schedule.

## Discussion

In the flowchart that has been developed, where the steps and activities to report progress in detail engineering with the use of BIM (see Figure 3) are highlighted, there are certain key activities that must be carried out for this to succeed. A prerequisite is the initial activities in the first step, where the necessary preparations for reporting progress from building information models are done. Here, it is critical to set the right abstraction level, by defining control objects, based on modeling objects, for each discipline. Status definitions for control objects must be established, and status requirements for each control object must be set towards each milestone in detail engineering, to reach a higher maturity through the desired quality levels.

To adapt the findings to the construction industry, it is crucial to do the necessary preparations for reporting progress using BIM in the first step. Defining a basic set of control objects and grouping these for each discipline would differ slightly from those in the oil and gas industry, because of different types of constructions and thereby also type and number of disciplines. Within the construction industry, the control objects for each discipline would also vary, depending on the type, size and complexity of a project. Table 7 illustrates a suggestion of possible control object groups with a basic set of corresponding control objects and modeling objects for the construction industry, using the structural discipline as an example. The control object groups and corresponding control objects for the structural discipline would differ based on the chosen load-bearing system. As a basis, the structural discipline is here split in concrete and steel. Within concrete, control objects are grouped in foundations, floors/slabs and walls/columns. Within steel, control objects are grouped in main steel and outfitting steel. Each control object group typically consist of one to several control objects. Similarly, each control object would typically consist of one to several modeling objects. There can be similar control objects for different control object groups. This can be used as a starting point for defining control object groups with control objects for the construction industry.

| Discipline | | Control object group | Control object | Modeling objects |
|---|---|---|---|---|
| **Structural** | Concrete | Foundations | Foundations | Foundations |
| | | Floors | Slabs | Slabs, Beams |
| | | Walls | Columns | Columns, Other vertical load-bearing systems |
| | | | External walls | External walls, Load-bearing structure for facade |
| | | | Internal walls | Internal walls, Elevator/Stair shafts |
| | Steel | Main steel | Trusses | Columns, Beams, Stay cables |
| | | | Columns | Columns |
| | | | Beams | Beams |
| | | Outfitting steel | Stairs | Stairs |

*Table 7: Possible control objects for the structural discipline in the construction industry*

Status definitions for control objects must be established for use in the construction industry. These can in principle be the same for both industries. Another similar term used in the construction industry is the level of detail or level of development (LOD). The LOD framework is an industry-developed standard to describe the state of development of modeling objects, and is a measure of the complexity of a building information model (Kunz and Fischer, 2012) or how detailed each modeling object is. A higher LOD number indicates a higher level of detail (Han *et al.*, 2015). There are six levels of LOD, which progresses at different rates depending on type of modeling object and discipline (Solihin and Eastman, 2015). The LOD levels addresses the amount of detail on each modeling object and usability towards other disciplines (Ramaji and Memari, 2016), while status definitions expands this to define quality and maturity of modelling objects, through control objects (AkerSolutions, 2014b). A comparison between statuses and LOD definitions has been made (see Table 8), and illustrates which LOD should be achieved to each status. They correspond well, with one exception. When status S3 is achieved, the control object is completed with final shape and location, and interfaces towards other control objects and disciplines are frozen. This corresponds with LOD 350. At the same time, LOD 350 is the highest level before detailing is completed. LOD 350 will therefore also include status S4, which is a further detailing of the control object that does not affect other control objects or disciplines. LOD on modeling objects could therefore still be used, but to support reporting progress from building information models, status on control objects should be defined and used.

| ENGINEERING STATUS DEFINITIONS | | | LEVEL OF DETAIL/DEVELOPMENT (LOD) DEFINITIONS | |
|---|---|---|---|---|
| STATUS | NAME | DESCRIPTION | LOD | DESCRIPTION |
| S0 | Defined | The control object is defined in the model. The shape can be as simple as a cube. | LOD 100 | The modelling object is represented as a symbol or generic representation. |
| S1 | Preliminary | Control object modelled with simplified shape based on preliminary design from previous stage and estimated information. | LOD 200 | The modelling object is represented as a generic object with approximate quantities, size, shape, location and orientation. |
| S2 | Released for verification/ IDC | Detailed shape with outer dimensions and location approved by own discipline. | LOD 300 | The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation. |
| S3 | Frozen interface | Control object completed with final shape and location. Verification/IDC comments implemented. Interfaces towards other control objects and other disciplines frozen. | LOD 350 | The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation, and interfaces with other building systems (disciplines). |
| S4 | Detail design completed | Detail design of control object completed and approved for construction. Detailing shall not affect interfaces to other disciplines and control objects. | | |
| S5 | Issued for construction | All necessary prefabrication, installation and commissioning information added. | LOD 400 | The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation, with detailing, fabrication, assembly and installation information. |
| S6 | As-built | Relevant as-built information implemented | LOD 500 | LOD 500 adds field verified representation (as-built). |

*Table 8: Comparison of status definitions (AkerSolutions, 2009) and LOD definitions (BIMForum, 2013)*

When the necessary preparations in the first step are done, the second step can be initiated. Initially, visual progress using BIM should be reported. By assigning color codes to the statuses, actual status of the control objects can be visualized in a BIM-based review software. To be able to report overall progress, it is essential to set a realistic estimate of control objects. Furthermore, calculating the weighted number of control objects for each status is also critical for calculation of a reliable overall progress for each discipline. In the third step, where the overall progress is connected to an engineering schedule, a prerequisite is to define relevant activities related to control objects for each discipline in the schedule, which is the same abstraction level as the overall progress report.

# Conclusions

A three-step process for reporting progress in detail engineering with the use of BIM has been developed, based on experiences from projects in the oil and gas industry. This process can be used as a basis for adaption towards projects in the construction industry. The majority of the existing research related to monitoring progress using BIM relates to construction and not detail engineering. What further differentiates the three-step process from similar research is the first step, which is a prerequisite for the last two. In the first step, principles from a PEM are applied. What differentiates the use of a PEM compared to knowledge management systems and stage-gate models is the execution level. Here, control objects and status definitions are defined for each discipline, and related to quality levels, which are crucial for being able to report progress using BIM. In the second step, both visual and overall progress can be reported using BIM. By adding color codes to status definitions,

progress can be reported visually, through control objects in the building information models. This makes it possible to see the maturity and quality of the building information models directly, including what is frozen and should by definition not be changed. Status is both quality and quantity. Overall progress can be reported through aggregating the actual number of control objects and statuses on these, compared to an estimated number of control objects. By weighting the number of control objects, the calculation of the overall progress can be more accurate. To connect the overall progress towards an engineering schedule in the third step, activities in the engineering schedule are defined based on control objects, so that progress can be reported directly from the building information models. The first two steps support the first part of the research question on how progress in detail engineering can be reported using BIM. Based on the first two steps, the last step supports the last part of the research question on how progress reporting can be connected to activities in an engineering schedule.

The main focus for the research has been to assess how engineering progress can be reported using BIM in detail engineering. The focus has been on execution processes and deliverables related to BIM. Further research will focus on adapting and testing the findings towards projects in the construction industry. A set of control objects should be developed and status definitions for all main disciplines should be adapted. With this in place, color codes should be assigned to the status definitions, to be able to report progress visually. Furthermore, the overall progress report should be refined for use in construction projects. Finally, a template with a set of activities based on control objects for each discipline for the use in an engineering schedule in construction projects should be developed, so that it will be possible to set progress on these based on input from building information models.

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## Paper 4

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# IMPROVING COLLABORATION BETWEEN ENGINEERING AND CONSTRUCTION IN DETAIL ENGINEERING USING A PROJECT EXECUTION MODEL AND BIM

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*SUMMARY: The construction industry is under pressure to reduce project delivery time and costs despite increased project complexity. A challenge is that engineering and construction are not well integrated. Usually engineering takes place during a given period, followed by construction. Demands for shorter delivery time, indicate that construction should be pushed in parallel with engineering, with better correlation between how one conducts engineering and plan to build. To address this, the construction industry would benefit from gathering knowledge and learn from other relevant industries. How can collaboration and transition between engineering and construction in detail engineering be improved, with the use of a project execution model and utilization of BIM? Research is based on case studies of major oil and gas projects. Data is collected through an EPC (engineering, procurement and construction) contractor and two engineering contractors. The projects have been executed as EPC contracts (design-build), where engineering and procurement is subcontracted. The paper assess how collaboration between engineering and construction can be improved with a combination of aspects related to process, people and technology. The first, process, is how parallelism between engineering and construction is based on frozen design, and how engineering can adapt to a construction sequence, by adjusting milestone requirements and deliver "right the first time". The second, people, is how relational contracts, with focus on relationship and common goals, can be used and how engineering teams can be selected and developed to support this. The third, technology, is how engineering can split building information models, to support fabrication.*

*KEYWORDS: BIM, concurrent engineering, integrated design and delivery solutions, joint venture, model split, project execution model, team development*

# 1. INTRODUCTION

In the construction industry, there is a trend towards larger and more complex projects, which makes them more difficult to manage (Whyte et al, 2016, Fischer et al, 2017). Larger projects, higher complexity and thereby increased risk in these projects, means that building owners, main contractors and engineering consultants (including architects) should focus on improved processes related to professional management of projects, increased interaction between the project actors, and increased exploitation of available and innovative technology. The Norwegian construction industry is highly decentralized, with many small companies and only a few large companies, and has challenges related to the need for more innovation and improved productivity, poor relationships between the construction parties and increasing competition from foreign companies on the domestic market (Bygballe and Ingemansson, 2014). The industry is also under pressure to reduce project delivery time and costs despite increased project complexity (Jaafari, 1997, Bogus et al, 2005). A challenge is that engineering and construction are not well integrated in current practice (Luth et al, 2013). Usually engineering takes place at a given period, followed by construction. Demands for shorter execution time, indicate that construction should be pushed in parallel with engineering. The engineering consultant prefers to think in a totality until detail engineering is finished, while the main contractor will follow a construction sequence that is cost effective for them. According to Berard and Karlshoej (2012), influence and inclusion of contractors in detail engineering in design-build contracts are important, because contractors then can receive deliverables suited for their construction sequence. This calls for increased focus on collaboration between engineering and construction in detail engineering. Compared to other industries, the construction industry has also been slow at technological development (WEF, 2016), partly due to cultural resistance (Sarhan and Fox, 2013).

As part of this development, the construction industry would benefit from gathering knowledge and learn from other relevant industries with experience in execution of large and complex projects (Tuohy and Murphy, 2015). Over the past 40 years, the oil and gas industry has focused on streamlining management and execution of large and complex projects and invested heavily in development of new technology. Furthermore, the Norwegian oil and gas industry has an international recognition for project management and active exploitation of technology (Sasson and Blomgren, 2011). Long-term participation in development of technologies to support offshore oil and gas projects in the North Sea, has made the supply industry competitive - both in Norway and in international markets (Mäkitie et al, 2018). Despite being two different industries, the similarities in project execution in the two industries are many, including project phases, actors, management principles and use of technology (Mejlænder-Larsen, 2015).

In this paper, I explore how a project execution model (PEM) is used, combined with the use of building information modeling (BIM), through projects in the oil and gas industry. A PEM is a generic breakdown of a project, and a structured way of managing and executing multidiscipline work processes, through all project phases (AkerSolutions, 2014b). It defines a logic sequence in critical project activities, where progress and quality requirements are aligned at significant milestones (Kvaerner, 2012b). Building information modeling (BIM) can be defined as a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Succar et al, 2012, p120). Knowledge gained by a project team during a project is often not retained and used on future projects. A crucial step is the conversion of this tacit knowledge to explicit knowledge, where only explicit knowledge can be integrated in the organizational knowledge base. Knowledge management can be used to support this transformation (Lindner and Wald, 2011). Knowledge management can be defined as "the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage" (Carrillo and Chinowsky, 2006, p2), and is critical for process improvement. A PEM is based on the principles of knowledge management. It is not a model per se, but a methodology used in all projects within the organization. The objective of a PEM is to secure predictability in project execution using a standard methodology well known to the project team, to ensure multidiscipline understanding and focus on common goals, and avoid rework (Kvaerner, 2012b). A PEM cannot be fully utilized without the use of a 3D design environment, which is a multidiscipline and object-based 3D design, integrated with a number of information systems, that serves as the main source of information (Kvaerner, 2012a), and corresponds to BIM in the construction industry (hereinafter called BIM). BIM is a central part of the work processes defined in a PEM and is used in all phases. BIM is not only used in the coordination of complex projects, but also to support management through enhanced collaboration and information sharing (Bryde et al, 2013).

This paper asks the following research question: How can collaboration and transition between engineering and construction in detail engineering be improved, with the use of a project execution model and utilization of BIM? Findings are based on studies of experiences from execution of large projects in the oil and gas industry. These have been executed as EPC (engineering, procurement and construction) contracts, which are comparable to design-build contracts in the construction industry, through an EPC contractor and two engineering contractors. How data has been collected and analyzed is elaborated as part of the research method. The findings that are emphasized in this paper have been grouped into three interdependent dimensions; process, people and technology. Combined, these can improve collaboration between engineering and construction in detail engineering. The first part, process, focus on parallelism between engineering and construction and how that relates to frozen design, how engineering can adapt to a construction sequence through milestone requirements, and "right the first time" deliverables. The second part, people, focus on relational contracts, based on a joint venture, and selection and development of an engineering team. The third part, technology, focus on how engineering can split building information models, to support fabrication. While BIM refer to the processes of modeling, collaboration and integration, building information model to refer to the object-based model (Sun et al, 2017). In the discussion, the findings related to process, people and technology have been compared to aspects related to integrated design and delivery solutions (IDDS) (Owen et al, 2009), to access the relevance of the findings to the construction industry. The paper concludes with a summary of main contributions and suggests avenues for further research.

## 2. RESEARCH METHOD

The research is qualitative, conducted as case study research, which involves an empirical investigation of a contemporary phenomenon within its real-life context (Yin, 2009). Because it is empirical, it relies on the collection of evidence, through the study of specific cases of interest. Data have been collected from three case projects in the oil and gas industry, through a Norwegian EPC contractor, a Norwegian engineering contractor (hereinafter called engineering contractor 1), and an American engineering contractor (hereinafter called engineering contractor 2). The case projects are delivery of topsides of production platforms on the Norwegian continental shelf, executed as EPC contracts (design-build). Topsides holds the facilities to process oil and gas from the reservoir in the seabed below, and have been designed and built for installation on steel jackets. The first case has been the topside for one of four Johan Sverdrup platforms, consisting of the utility and living quarters, which started detail engineering in 2015 (Kvaerner, 2015b). It is executed as a joint venture between the EPC contractor and engineering contractor 2 as engineering and procurement contractor. The second case has been the topside for the Edvard Grieg platform, mainly consisting of a living quarter and utility module. It was completed in April 2015 (Kvaerner, 2015a). The third case has been the topside for the Eldfisk platform, mainly consisting of a living quarter and utility module. It was completed in April 2014 (Kvaerner, 2014). Both were executed with the EPC contractor and engineering contractor 1 as engineering and procurement subcontractor. They were completed as planned, on time and to the specified quality. The three case projects were selected by the EPC contractor, based on the information they could contribute with on the use of the PEM and utilization of BIM.

Empirical data have been collected through interviews. 15 semi-structured interviews have been carried out, with the use of interview guides, from March 2013 to June 2016 (see Table 1). This includes nine interviews with the EPC contractor, three with engineering contractor 1 and three with engineering contractor 2. The average length of the interviews has been 1 hour 30 minutes. Each interview has been conducted with one to three interviewees in key positions, mainly at the management level. The empirical data collected through the interviews have been supplemented with document studies, through relevant company- and project documents. The focus has been to corroborate the data collected through interviews, to verify what has been mentioned in the interviews, and to acquire new or additional information necessary to a full understanding (Yin, 2009).

The stepwise-deductive-inductive (SDI) method (Tjora, 2012) has been applied to analyze the collected data. The principle of this method is to work in a series of steps from data to concepts or theories (inductive), and then go back to the data to empirically verify those concepts or theories (deductive). The collected data from the interviews has been transcribed and "empiric-close" coding that reflects the contents of the text that has been developed. The codes have been sorted into larger groups of themes, called categories, and used as a basis to develop concepts that capture central characteristics of observations and findings. The goal has been to develop a few themes (categories) that extract the potential from the empirical data and addresses the research questions. The inductive process in the SDI method is similar to a thematic coding approach (see Robson (2011) for a discussion), where all parts of the data are coded and labeled, and sorted into potential themes. The codes and themes are determined by analyzing

the data, based on its relevance to the research questions. The themes serve as a basis for further analysis. This approach is what Kvale (2009) calls "concept-driven" coding, where the codes have been developed in advance, through parts of the data or the existing literature. The main difference between this approach and the inductive process in the SDI method is what Kvale (2009) calls "data-driven" coding, where no codes have been defined in advance, but are developed through the analysis of the data. This is similar to, and based on a "grounded theory approach" (see Robson (2011) for a discussion), where the goal is to develop a theory "grounded" in the data, where the codes are developed based on the interaction with the data, through the interpretation of the meanings in the text. Data analysis has been supported using computer-assisted qualitative data analysis software (CAQDAS), which refers a software that is specifically designed for analyzing qualitative text (Sinkovics and Alfoldi, 2012). The SDI method follows a linear approach, but the process is iterative. It might well be that after having defined categories or developed concepts (inductive), there is a need to go back to generate more empirical data to support or expand these (deductive). This was the case in my research, where engineering contractor 1 and 2 were added in 2016 to expand the empirical data. Using CAQDAS helps to facilitate an iterative process (Sinkovics and Alfoldi, 2012).

*TABLE 1: Overview of interviews conducted as part of data collection*

| Interview date | Interview duration | Inteview source | Interviewee roles |
|---|---|---|---|
| 130311 | 01:55 | EPC contractor | *Information Manager, Project Manager* |
| 130419 | 01:10 | EPC contractor | *Information Manager* |
| 131126 | 01:20 | EPC contractor | *Information Manager, PEM Manager* |
| 140314 | 02:00 | EPC contractor | *Project Manager* |
| 141218 | 03:12 | EPC contractor | *Project Manager* |
| 151016 | 01:25 | EPC contractor | *Project Manager* |
| 160428 | 01:26 | Engineering contractor 1 | *Engineering Manager (2)* |
| 160617 | 01:37 | Engineering contractor 1 | *Engineering Manager (2)* |
| 160620 | 01:25 | Engineering contractor 2 | *Engineering Manager* |
| 160620 | 01:27 | Engineering contractor 2 | *Information Manager, CAD Manager, Data Manager* |
| 160620 | 00:48 | EPC contractor | *Integration Manager* |
| 160621 | 00:47 | Engineering contractor 2 | *Deputy Project Director* |
| 160621 | 00:43 | EPC contractor | *Construction Method Lead* |
| 160621 | 01:01 | EPC contractor | *Integration Manager* |
| 160624 | 02:27 | Engineering contractor 1 | *PEM Manager* |
| **15** | **22:43** | **TOTAL** | |
| | **01:30** | **AVERAGE** | |

## 3. FINDINGS

The findings are divided into three parts. The first part is related to process, and looks closer at parallelism and construction sequence. The ambition is to execute the project in as short time as possible and have as high parallelism between engineering and construction as possible, but at the same time meet the quality requirements to the client. To improve collaboration, it is important that there is a correlation between how one conducts engineering and how one plan to build. The engineering consultant can support this by adapting to a desired construction sequence to the main contractor. The second part is related to people, and focus on the shift from transactional towards relational contracts. Establishing a joint venture will increase the motivation to collaborate for the contracting parties. What will further improve integration is the composition and development of the engineering team. The third part is related to technology, and assess how engineering deliverables must be adapted to construction needs. Building information models are split according to the requirements of the main contractor, to be able to define and control what is sent out for fabrication.

### 3.1 Process

#### 3.1.1 Parallelism and frozen design

With parallelism, a project is executed in phases, but engineering and construction are overlapped to save time (Jaafari, 1997). Integration of engineering and construction is not new, and similar terms and techniques have been

used to respond to the time and cost pressures in projects (Jaafari, 1997). Parallelism is similar to concurrent engineering, where the aim is to reduce the total delivery time and cost of a project by overlapping activities that are normally performed in a sequence. This involves grouping deliverables into work packages so that construction can start before engineering is complete (Bogus et al, 2011). According to Lee et al. (2005), concurrent engineering and construction, has gained popularity due to the increased demand for shorter time frame of projects. The more parallelism between engineering and construction there is in a project, the greater demands are put on the participants in that they know what the construction sequence and the quality requirements of the project are. This is similar to what Succar (2009) has defined as "BIM stage 2", where engineering and construction are in parallel, and driven by construction providing design-related services, and engineering increasingly adding construction and procurement information into their building information models. Similarly, Anumba and Evbuomwan (1997) define the aim of concurrent engineering as to reduce lead times and improve quality and cost by integrating fabrication in detail engineering, and thereby maximizing parallelism. Fabrication allows the parallel production of the physical components and systems, which is much faster than the sequential construction of these components and systems on site (Fischer et al, 2017). Furthermore, prefabrication can increase construction efficiency and enable better sequencing in the construction process, and thus possibly reduce project delivery time and construction cost, compared to traditional construction methods (WEF, 2016).

Detail engineering, as defined in the PEM, developed by the EPC contractor and engineering contractor 1 (Kvaerner, 2012b), consists of four stages with corresponding milestones (see Fig. 1). In the first, stage 2A, with milestone M2A, the design concept is confirmed, and critical purchase orders are set. At stage 2B, with milestone M2B, the main layout and main structures are confirmed. When milestone M2C in stage 2C is reached, the 3D model, corresponding to building information model in the construction industry, shall be clash free and complete, except for final detailing. At the last stage, 3A, with milestone M3A, all disciplines have completed their 3D models (hereinafter called building information models), to a level ready for fabrication. EPC contracts start with engineering and procurement, shown in parallel from stage 2B. Engineering and procurement continue in parallel to the end of stage 3A. Here fabrication (construction) is initiated and shown in parallel with procurement. The EPC contractor usually start fabrication at the end of detail engineering, at milestone M3A, as part of construction.
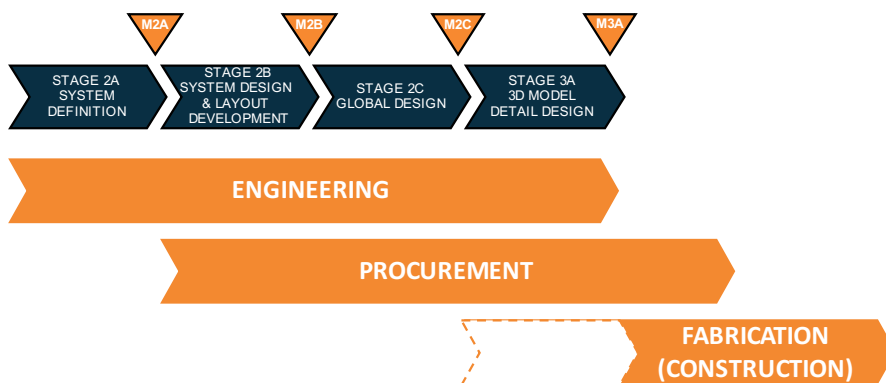


*FIG. 1: Stages and milestones in the PEM in detail engineering compared to project steps (AkerSolutions, 2014a, AkerSolutions, 2011)*

The duration from project start to completion and hand-over is set by the client. Shorter duration requires a higher degree of parallelism between the project phases. Projects can get a considerably compressed total completion time because of parallelism. The question is how far one can drive parallelism in detail engineering. It is possible to start fabrication much earlier with parallelism, with engineering processes that runs in parallel with construction. A prerequisite for this is that the relevant parts of a building information model have reached a defined quality level at the milestone where the objects are frozen, and by definition should not be changed. This corresponds to the M2C milestone (see Fig. 1). This means that the location of the objects and all interfaces towards other disciplines in the relevant objects of the building information model should be frozen. Critical actions from the design review should be implemented and the building information model should be clash free. The objects will

be further developed, but cannot affect other disciplines or other parts of the design after this point. All objects go through a maturity chain, but with different timing (AkerSolutions, 2014a). There will always be a discipline that sets the premises for others. In the construction industry, this is often the architectural discipline. There will therefore be some difference in maturity of the building information models between the disciplines at each milestone. The engineering contractor can start deliverables from the parts of the building information models that are frozen, which then can be used by the EPC contractor to start fabrication, as part of construction. The EPC contractor will always try to fabricate components as early as possible, while the engineering contractor will need to mature the design. Deliverables, including drawings that are issued after the M2C milestone have a much less risk of changes in construction.

The higher level of ambition towards early fabrication, the more detail engineering can get out of sequence. In the Edvard Grieg case project, the aim for the EPC contractor was to obtain detailed information to start fabrication earlier than the M2C milestone, as found in the PEM,. To achieve this, there were a considerable overlap between engineering and construction. As fabrication started prior to the M2C milestone, the relevant objects in the building information model were then not yet frozen. This resulted in a lot of added work in the end for the engineering contractor, because of rework, to clean up what had been done related to temporary assumptions. To push deliverables prior to frozen design, will have an increased cost of engineering. There is a considerable risk that not everything is correct when released that early. The earlier deliverables, including drawings, are issued, because of parallelism, the greater the risk. Engineering get out of sequence, which leads to a higher time consumption. The principal assumptions used in engineering are not followed, because information is released before it is frozen.

### 3.1.2 Construction sequence and milestone requirements

With parallelism, it is important to be aligned in the sense that there is a correlation between how engineering is conducted and the planned construction sequence. Normal practice is to produce a design based on no particular construction sequence (Luth et al, 2013) To achieve improvements in construction productivity, the actors must ensure that the actual construction process is kept in mind during engineering (WEF, 2016). The main contractor has developed a construction sequence that is time and cost efficient. It is important that the engineering consultant manage to adapt and design according to that. The main contractor must communicate with the engineering consultant what they need to deliver and when. It is basically to divide the construction in accordance with how it is going to be built, with a certain sequence from the ground and up. At the Johan Sverdrup case project, the EPC contractor therefore spent sufficient time with the engineering contractor at the start of the project to explain what they required of engineering deliverables, through requirements to what status objects in the building information model should have, to fulfill the desired quality level at each milestone.

Adding construction sequence is a prerequisite for the objects in the building information models to support fabrication. It means that the fabrication order can be determined logically as an integrated part of the design process (Luth et al, 2013). To deliver according to a desired construction sequence, require focus on "right the first time", which is delivering the necessary information right the first time and thereby reducing the amount of rework (Pheng Low and Yeo, 1998). From productivity considerations, it will be an ideal desire in all contexts. The challenge is always to ask for the right information at the right time, e.g. fabrication may early on only need preliminary information for planning purposes and thereby not require final information. The PEM supports "right the first time" through defined milestone requirements for all disciplines to all stages in detail engineering. The objects in the building information models therefore must have reached a certain status at each milestone in detail engineering. If some disciplines go too far and others too short on a milestone, it will not be "right the first time".

To make sure the engineering consultant has progressed as far as required to start deliverables to construction, their milestones must be checked against the corresponding milestones to the main contractor. The methodology is based on the fact that the requirements the main contractor has made for the milestones, in terms of what the disciplines to the engineering consultant should deliver and to what status, to reach a desired quality level at each milestone, has been adapted by the engineering consultant to support the construction sequence. At the Johan Sverdrup case project, the milestone requirements for each discipline in detail engineering were compared through a GAP analysis, to see if the engineering contractor were close to fulfilling the milestone requirements to the EPC contractor. They both identified the gaps between the milestones and identified where the engineering contractor needed to increase their milestone requirements.

## 3.2 People

### 3.2.1 From transactional to relational contracts

When entering an EPC contract as an EPC contractor, with control over engineering, procurement and construction, rational considerations can be made in order to reduce the risk and optimize the bottom line. The EPC contractor then determines the optimal sequence and the desired order of project deliverables. When engineering, procurement and construction are split between separate companies, the interests of one may not always be favored by the other, because of different objectives. With engineering and procurement on a subcontract, there can be different contractual arrangements between the EPC contractor and the engineering subcontractor. The engineering subcontractor will work in accordance with their objectives, that often do not correspond with the objectives to the EPC contractor. According to Jaafari (1997) each party in a project tends to manage their own scope in a way that minimizes their own exposure to risks and maximizes their gain, which may lead to divergence between objectives of the parties and project objectives. Holding the parties accountable for their own scope and price will drive the project towards individual optimization (Matthews and Howell, 2005).

The main distinction between different contractual arrangements are based on contractual relationship and organizational structure (Mesa et al, 2016). The former defines the contractual responsibilities, risk allocation, and the form of compensation methods for selecting participants. The latter defines how the participants communicate and report to each other. According to AIA (2007), traditional contracts often create boundaries that rarely overlap, with clearly defined responsibilities for the parties in a project, and consequences if failures are made. Traditional construction contracts are made between two companies at a time, and focus on transferring risk, which often means that incentives of the parties and the project are not aligned. Current contractual agreements, rather than reinforcing the need to bring the members of the project team together to create innovate solutions, drive them apart to work in independent silos (Fischer et al, 2017). The focus is on transaction between the parties. Relational contracts on the other hand, focus on the relationships that are necessary for successful execution and completion of a project. A contract which is based on a relationship of trust between the parties, and where responsibilities and benefits are apportioned fairly and transparently, is called relational as opposed to transactional (Lahdenperä, 2012). Similarly, Matthews and Howell (2005) states that relational contracts minimizes transactional costs because the parties are bind together in a partnership through the whole project. It is emphasized that it is important to be aligned related to engineering deliverables between the main contractor and engineering consultant. This can be reflected through a joint venture.

### 3.2.2 Joint venture

At the Johan Sverdrup case project, the EPC contractor and engineering contractor 2 have established a joint venture for a jointly executed EPC, where a new operating unit is established to take on the contract. The client did not award the contract directly to the EPC contractor or engineering contractor 2, but to the joint venture, which in principle is a separate legal entity. Between the parties, there is not much overlap in responsibilities. The EPC contractor will handle construction and do a small amount of engineering to support the engineering contractor. The two parties are not trying to compete, but rather to collaborate. How they share reward and risk among themselves is reflected in their internal contract. When engineering contractor 2 goes into a joint venture, like in the Johan Sverdrup case project, being responsible for engineering and procurement, their intension is to take a proportionally large share of the risk. They are both "joint and several" responsible, which means that they are jointly and severally bind to each other and to fulfilling all terms, conditions and requirements in the contract (Matthews and Howell, 2005). According to Owen et al (2010), temporary joint ventures can be established to provide cost, time and delivered quality benefits through more integrated processes. The understanding throughout a joint venture, as a relational contract, is that the two parties are mutually dependent of both performing, and they share profits on the bottom line in a percentage distribution. If any of the parties do not manage to deliver, there might not be a bottom line to share. This means in practice that if one part is not performing, it has a consequence for the other. It is a model that better prepare for an improved collaboration between engineering and construction, because they have common goals. The parties are only reimbursed for all verifiable direct costs that incur, and only share the gross profits from what is left of the cash balance at the end of the project. They should be motivated to perform and deliver as planned and agreed. If not, the parties can go from sharing profits to covering deficits afterwards. For the EPC contractor, this is the most effective, because they do not need to be as aggressive in trying to follow up the engineering contractor and their disciplines as in a traditional subcontract. They are partners, and both knows what applies. They demonstrate vulnerability by taking a large partner risk, which indicates high

trustworthiness (Swärd, 2016). Trust, in this case, can be defined as the willingness to be susceptible to actions of another party, based on the expectations that the other party will perform a particular action, regardless of the ability to monitor or control that party (Mayer et al, 1995). Trust not only facilitates information sharing but also enhances productivity (Robbins and Judge, 2012).

Looking ahead, the parties in the joint venture can attain efficiency improvements and simplifications. Using the same joint venture when entering a new project, project management can use the experiences and best practices in the project they just have executed, up against a new project. The new project can be looking for improvements through increased efficiency. By encouraging to develop the relationship between the participants, managers can help initiate cooperation and coordination processes that reinforce one another (Bygballe et al, 2016).

### 3.2.3 Integrated project delivery

With a fragmented construction process, through separated design and construction, there has been a need in the construction industry to move towards a better coordination of participants and more collaborative approaches (Mesa et al, 2016). Relational contracting has been offered as a solution to these challenges (Lahdenperä, 2012). Integrated project delivery (IPD) proposes to be a response to this, and initially emerged in 2003 when a group of project participants bound themselves jointly and severally to each other and to the fulfilment of the contract to the client (Lahdenperä, 2012). The construction industry has started to use IPD in an effort to increase collaboration and improve performance (Mesa et al, 2016). IPD is a relatively new concept that is evolving and is still far from being universally standardized (El Asmar et al, 2013). As a relational contract, a joint venture has many of the same characteristics as an IPD agreement.

According to Fakhimi et al (2017), IPD has six characteristics that differentiate it from traditional types of contractual arrangements, such as the traditional design-bid-build and the more collaborative design-build contracts. The first is a multiparty contract. In contrast to a joint venture, where the agreement often is between the main contractor and engineering consultant, the IPD agreement must at least include the client, engineering consultant and main contractor (Lahdenperä, 2012, Mesa et al, 2016, Hanna, 2016), with coordination and joint commitment implemented through a collaborative multi-party agreement (Lahdenperä, 2012, El Asmar et al, 2013, Hanna, 2016). The second is early involvement of key participants. Early involvement and collaboration between key participants, is essential for project success (El Asmar et al, 2013), and refers especially to the early involvement of the contractor. IPD also emphasizes the early involvement of a broader group of subcontractors as essential (Lahdenperä, 2012). The third is collaborative decision making and control. Through a contractually defined relationship, all key IPD participants are established as equals and supports collaboration and consensus-based decisions. Equally important for a joint venture and IPD is that the relationship requires honest and open communication. Only then can the parties respect each other and establish trust (Lahdenperä, 2012). The fourth is shared risks and rewards. IPD uses a relational structure with jointly shared risk and reward to enable and reinforce collaboration (Fischer et al, 2017), which is similar to a joint venture. The participants collectively manage and appropriately share risks (El Asmar et al, 2013, Mesa et al, 2016). The basis for reimbursement is that the participants collaboratively establish a target price for the project, and then work together to maximize the value that the client receives (Mesa et al, 2016). An approach where the key participants bear the risk jointly and are rewarded based on the success of the overall project, encourages the actors to consider each other's views and to cooperate effectively (Lahdenperä, 2012). The fifth is liability waivers among key participants. A joint liability minimize the client's risks and make the overall performance more efficient (El Asmar et al, 2013, Lahdenperä, 2012). The sixth is jointly developed project goals. The individual participants will only succeed by achieving the overall project goals (Fischer et al, 2017).

### 3.2.4 Team selection

Selecting the right people for the project team is crucial for success, because it sets the proper basis for cooperation (Zimina et al, 2012). When setting up an engineering team in the joint venture at the Johan Sverdrup case project, project management emphasized the importance of mixing new and experienced people. Some people are handpicked into the engineering team. New come in and create a blend of people with different qualifications and new ideas. An A-team is not made up of grade A people in all positions, but with a cross section of different people that have the competence and right skills and can work together. It is important to match the strength of the people to the risk areas. This is similar to a team composition in IPD projects, where a well-balanced team need members with technical expertise, problem solving and decision-making capability, and interpersonal skills. Because few

team members have all these capabilities, the members should be chosen to assure that all these capabilities are represented within the team (Hackman, 2011, Robbins and Judge, 2012). Choosing the right people are not only those with necessary knowledge and experience, but those who also are open towards working together in an integrated team with a clear understanding of the common goals. The project comes first, before the interests of their organization (Fischer et al, 2017).

### 3.2.5 High-performance team

When the engineering team is in place, the focus should be on developing a high-performance team, which is cross-functional, multidisciplinary and integrated (Fischer et al, 2017). According to project management in the Johan Sverdrup case project, a high-performance team requires focus on four aspects. This includes a clearly defined scope of work, creating a common team identity, clearly defined milestones, and reward and recognition (see Fig. 2).



*FIG. 2: Four aspects that makes a high-performance team*

**Scope of work:** There must be put considerable effort at the start of the project to get the team organized properly, to have workshops focusing on the scope of work, and present it so that the entire team get a common understanding. It is important that those assigned to work on the project are carefully selected and prepared (Matthews and Howell, 2005). At the start of the Johan Sverdrup case project, project management did a thorough induction for everyone, where the contract and the scope of work was explained. Project management explained how to secure profits, how to interact with the client, how the PEM should be used, and the interface between engineering and fabrication, so the team could understand why and how the interaction would function. It was emphasized that nobody were authorized to work on anything on the project unless they knew how the parties in the joint venture were going to get paid for the work. They should be commercially conscious to what mechanisms apply in the contract, and act in accordance with those. According to Swärd (2016), early encounters by management can be significant for initiating positive relational processes, in this case between the EPC contractor and engineering contractor 2. This is similar to an IPD project, where a common understanding of the project values and goals are developed, and clearly communicated to all project participants (Fischer et al, 2017).

**Team identity:** Co-location is designed to improve the progress and flow of the project, and is a collaborative execution of work by the project team in a single location, augmented by virtual collaboration tools (Fischer et al, 2017). They act as one team, where the focus is on identifying with and getting the right outcome for the joint venture, that by definition is good for both parties, and subsequently for the client. At the Johan Sverdrup case project, the engineering team consists of people from both parties, but within the joint venture, it is all about a common team identity. The entire engineering team is co-located with people from engineering contractor 2, supported by people from the EPC contractor. This is in line with an IPD project, where the team is co-located and rely on collaboration and rapid feedback from others in the team (Lahdenperä, 2012). The project team operates as a virtual organization committed to the project. It is not organized to optimize the outcome of individuals or their companies (Fischer et al, 2017).

**Milestones:** Project management should have a big push on milestones and getting hold on the milestones to be met ahead. Everyone in the team is supposed to be fully aware of this. They should reach out to everyone by communicating and explaining what each must do to contribute to fulfill the milestones.

**Reward and recognition:** According to Hackman (2011), a reward system provides recognition and positive consequences for the team performance. Team-focused recognition sustain collective motivation and encourage team member to think of the team rather than the individuals. The milestones that have been fulfilled and picked for special attention should be celebrated, to keep the morale and team spirit up.

## 3.3 Technology

### 3.3.1 Model split towards fabrication

When the disciplines in an engineering team start working without having to split the building information models towards a specific main contractor in detail engineering, they work relatively unhindered. The main contractor can have special requirements towards construction, to be able to define and control what is sent out for fabrication. This should be reflected in the model split. Instead of working with the entire construction, the engineering consultant must then concentrate on working in specific areas. All disciplines are basically having to work in these areas to make sure that engineering progresses in accordance with the requirements towards fabrication, so the main contractor can get the right information at the right time. The engineering consultant must therefore adapt their building information models in accordance with the needs of the main contractor. The more adaptation needed, the more time and effort is required by the engineering consultant.

Various EPC contractors may have slightly different preferences to how they want the model split towards fabrication, depending on the yard, how many production halls they have, how much the cranes can lift etc. From the start of the project, they need to get the construction sequence reflected in the building information models. Engineering contractor 1 and engineering contractor 2 have both defined generic model splits, which is not adapted towards how a specific EPC contractor would prefer it. The generic model split is made based on a logical engineering setup with modules, such as the living quarter module and utility module in the case projects, and areas within each of these modules. These will be adapted towards each specific EPC contractor, so that they can be completed at given milestones, and fabricated and assembled to a complete construction. Engineering normally stops at area. A more detailed spilt, in sections within each area, results in increased complexity, with many added interfaces, and is considered an additional service with additional engineering cost, since that is engineering that should be done as part of fabrication (see Fig. 3).
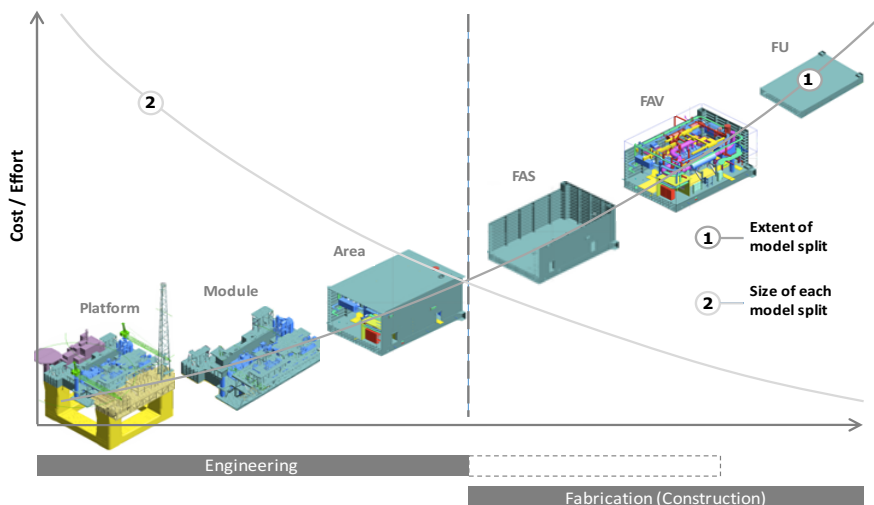


*FIG. 3: Model split in engineering and fabrication in EPC projects. Adapted from Kvaerner (2016)*

Sections, called fabrication assemblies, are defined by the EPC contractor to control the parts that are sent out for fabrication. Sections are similar to what Jaafari (1997) define as clusters, referring to particular parts that can include relevant procurement and construction activities. Each cluster can be assigned to a team and executed as an integrated part. Each fabrication assembly can be split in a FAS (fabrication assembly section), a structural block, which is a container for fabrication purposes. Installations from all other disciplines are assembled and added together to a FAV (fabrication assembly volume). Separate substructures, which are called FU (fabrication units), can also be added, to complete the fabrication assembly. Fabrication assemblies are designed with standardized dimensions so that they are moveable and able to be transported and lifted by a crane. All necessary documentation, including drawings, should be related to each fabrication assembly. At the Johan Sverdrup case project, the EPC contractor were part of the engineering team from day one, and supported engineering contractor 2 in the splitting of the building information models, to fit into different sections for fabrication. The model split created extra work because of the detailed split for fabrication purposes, which resulted in objects that had to be divided and attached to several sections. Engineering contractor 2 produced far more fabrication-related deliverables than usual. The deliverables, including drawings, were produced by a specific model split, in the same way, at the same time, and to the desired quality as fabrication wanted it.

### 3.3.2 Constructability

The main contractor can provide the engineering consultant with recommendations on constructability, based on best-practice solutions. Correspondingly, the engineering consultant can early on provide the main contractor with thorough understanding of the engineering process, which is fundamental for a successful project execution. Similarly, Luth et al. (2013) states that knowledge and methods on construction sequence and construction means can be incorporated in the building information models, in order to reach a sufficient quality level to produce drawings for construction. Not including construction knowledge in the design will likely lengthen the project duration and make it more expensive, because time and effort are required for redesign or for inefficient construction (Fischer et al, 2017). Often, building information models developed by engineering consultants do not meet the needs of contractors, because the focus is towards developing the design and producing construction drawings. Contractors often end up having to recreate the building information models because they are incomplete, inaccurate and/or ill-defined in scope (Nepal and Staub-French, 2016). During the first months of detail engineering at the Johan Sverdrup case project, the EPC contractor presented and handed over documentation to the main disciplines on constructability, that have been developed throughout the years. This included describing practical matters, e.g. how much space is needed to assemble bolts and access to welding in narrow spaces. The engineering contractor could then early on implement the experiences from the EPC contractor into the building information models. If the engineering contractor develops the building information models in accordance with the recommendations on constructability, the EPC contractor will spend less time in construction. According to the EPC contractor, they have managed to get 80-90% of their preferred solutions implemented. The EPC contractor continuously try to evolve and transfer documentation on constructability towards new projects.

## 4. DISCUSSION

## 4.1 Process, people and technology

When conducting research on collaboration between engineering and construction in detail engineering, it became evident that the findings could be grouped into three dimensions; process, people and technology, which are closely related and mutually dependent. Process, people and technology are also identified as categories used to classify challenges and benefits in an integrated design process (Rekola et al, 2010). Process is about focusing on integrated work processes. People is about involving people with the right skills, both technical and collaboration skills, and commitment to a team approach. Technology is about having a set of technologies and capabilities for collaboration and automation (Sacks et al, 2010).

The first part, on how frozen design determines the degree of parallelism between engineering and construction, and how engineering can adapt to a construction sequence by adjusting milestone requirements, using a PEM, and deliver "right the first time", is related to process. The second part, on the transition from transactional to relational contracts, and importance of selecting and developing the engineering team, is related to people. The third part, on how engineering can split building information models to support fabrication through a desired construction sequence, is related to technology (see Fig. 4).
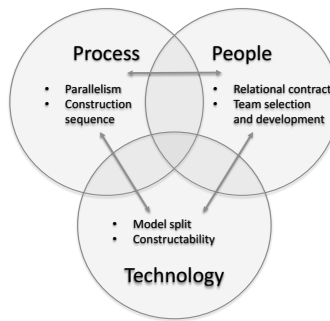
*FIG. 4: Findings related to process, people and technology*

A similar framework is the Product-Organization-Process (POP) model, which has been defined as part of Virtual Design and Construction (VDC), a term used in parallel with BIM in the construction industry, where a combination of products, organization and processes shapes the success of a project (Kunz and Fischer, 2012, Fischer et al, 2017). Product in the POP model is based on the development and use of BIM and can therefore be related to technology. Organization in the POP model is based on team development, and can be related to people. Process in the POP model is about work processes and can be related to process.

## 4.2 Relevance to the construction industry

The IDDS approach aims to utilize BIM and make sure that effective execution of construction projects is based on a combination of process, people and technology, and the interplay between these. IDDS consist of four main elements; collaborative processes, knowledge management, enhanced skills, and integrated information and automation systems (Owen et al, 2009). Knowledge management can be equally related towards findings on process, people and technology. Collaborative processes can be related to findings on process. Enhanced skills can be related to findings on people, while integrated information and automation systems can be related to findings on technology (see Fig. 5). The main challenges and focus for future development towards projects in the construction industry, that each of these elements address, have been briefly identified. This is followed by how key findings on process, people and technology can address these, which increases the relevance to the construction industry.
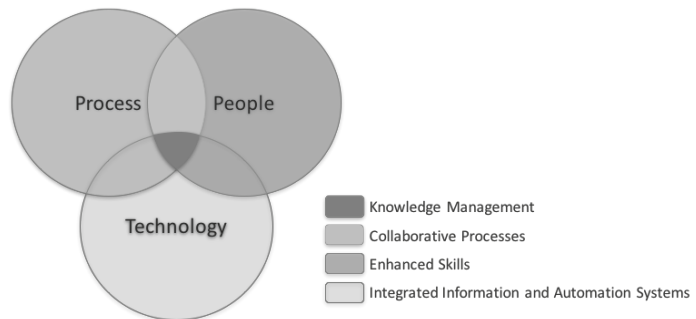


*FIG. 5: Relation between process, people and technology and the four elements of IDDS. Adapted from Owen et al (2010)*

**Knowledge management:** Knowledge management is applied by codifying, using and updating important knowledge and business processes, and is only done in a few leading companies (Owen et al, 2010). The use of a PEM is knowledge management in practice. It is used in all projects, and is the documented experience for how to execute and deliver projects (AkerSolutions, 2014a). The PEM, as developed by the EPC contractor and engineering contractor 1, is based on the knowledge areas in PMBOK (PMI, 2013), especially the Project Integration Management knowledge area, with focus on actions that are crucial to a controlled (managed) project

execution. The PEM has reflected this in a three-level pyramid, with the strategic level on top, followed by the control level and execution level. The strategic level describes the life cycle of a project, split into phases and requirements for each phase. The Control level describes how phases are broken down into multidiscipline stages with defined objectives and milestone requirements. This is similar to the principles of a stage-gate process, where proper documentation must be provided at each gate or decision point, to determine if a project will go ahead to the subsequent phase (Cooper, 1990). What differentiates the PEM compared to other knowledge management systems and stage-gate models is the execution level. The execution level contains all management and execution disciplines` work processes and activities (Kvaerner, 2012b). The strategic and control level is more generic and should be used in all projects. The execution level is much more comprehensive than the first two, and the extent of use will depend on the type, size and complexity of the project.

**Collaborative Processes:** Better coordination and integration is essential to improve design and delivery. To facilitate this requires collaboration combined with an effective knowledge management system. There might be additional benefits by adopting new methods to work processes being developed in other industries (Owen et al, 2010). The degree of parallelism, and thereby the transition from engineering to construction, is determined by the status of the objects in the building information models at the relevant milestones, as defined in the PEM. The basis for fabrication should be released when the design assumptions are in place, at the milestone where the relevant objects in the building information models are frozen. The main contractor must describe the construction sequence for the engineering consultant, so that they manage to deliver in accordance with that. This is supported through alignment of milestone requirements, to make sure engineering has come as far as required at all milestones, to deliver "right the first time".

**Enhanced Skills:** Project managers need to focus on and select people with a combination of technical knowledge and integration experience. Knowledge from previous projects combined with in-depth knowledge of current requirements will improve work processes between and within project phases. It is important to develop shared knowledge and skills, to be able to effectively perform integrated work processes. Having main contractors contributing to early input to key project decisions, will allow the use of beneficial construction methods, such as increased off-site work and automation (Owen et al, 2010). Selecting people with the right skills to the right positions is essential. They should preferably have the required competence, have previously worked together and have worked on similar type of projects. The main advantage of a relational contract, such as a joint venture, is its potential to align the objectives of the project team with project objectives. Establishing a joint venture with a common bottom line and common goals, will increase the motivation to integrate for both contracting parties. The main contractor can provide the engineering consultant with best practice solutions for increased constructability, to reflect construction needs.

**Integrated Information and Automation Systems:** Integrating physical work processes for fabrication in the design will increase the overall project performance. This includes extracting fabrication information from the building information model. Part of the industry is moving towards partial integration between engineering, procurement and construction (Owen et al, 2010). The engineering consultant must split the building information models according to the needs of the main contractor, to be able to define and control what is sent out for fabrication. The building information models are split in sections with standardized dimensions, called fabrication assemblies, which should include drawings and all other relevant information.

## 5. CONCLUSIONS

This paper has identified how collaboration in detail engineering between engineering and construction can be improved, based on studies of experiences from projects in the oil and gas industry. The main contribution to research is the holistic approach, where the findings related to both process, people and technology must be considered to improve collaboration between engineering and construction. This is supported with the use of a PEM, in combination with utilization of BIM. The findings related to process, people and technology is by no means exhaustive, but outlines the most salient aspects from the research. The first dimension, process, is related to parallelism and construction sequence. It is emphasized that construction can be pushed in parallel with engineering at the milestone, as defined in a PEM, when the building information models are developed to a quality level so that relevant objects and interfaces to other disciplines are frozen. Furthermore, the main contractor has made a construction sequence, which the engineering consultant must know and deliver in accordance with. Necessary requirements should therefore be aligned with the milestones to the engineering consultant, so that the

disciplines can fulfill these and satisfy the main contractor's construction sequence and deliver "right the first time". The next dimension, people, is related to the use of relational contracts and engineering team development. The scope here has been on a relational contract based on a joint venture and compared to an IPD agreement. When risks and profits are shared, the incentives for the project to succeed are higher for the parties to fulfill. They are mutually dependent on each other, all verifiable costs are compensated for, and profits are shared at the end of the project, based on a predefined distribution. Furthermore, it has been emphasized that to succeed requires selection of the right people from both parties in the engineering team, and develop these to a high-performance team. The last dimension, technology, is related to model split and constructability. The focus here has been on adapting the design towards fabrication. Building information models must be split in modules and areas to ensure that fabrication can get the right information at the right time, according to the milestone requirements, as defined in a PEM. With input from the main contractor, the engineering consultant can focus on constructability, which optimizes the engineering process and secures a more efficient construction process for the main contractor. Addressing the challenges related to process, people and technology, using IDDS, to the findings in this paper, increases the relevance to the construction industry. To summarize, the findings fulfill the first part of the research question, on how collaboration and transition between engineering and construction in detail engineering can be improved. The findings related to process and technology also directly fulfill the last part of the research question, on the use of a PEM and utilization of BIM. Further research will focus on adapting the key findings related to process, people and technology towards projects in the construction industry.

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## Paper 5

Mejlænder-Larsen, Ø. (2015). **Using a change control system and BIM to manage change requests in design.** *Proceedings of the 32nd International CIB W78 Conference*; 549-558.

# Using a change control system and BIM to manage change requests in design

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## Abstract

There are different types of changes in construction projects. Some have dramatic consequences, are costly and time driving, while others are insignificant. Today, there are few satisfying control systems to handle internal design changes or changes from the client. The changes are often handled manually and implemented without identifying possible consequences. It is essential to get control of changes because of the cost and schedule impact. Could changes in construction projects be better controlled with a change management tool that uses building information models (BIM) to identify consequences? This paper introduces a system for controlling changes; internal changes or changes to initial requirements from the client, and assesses how BIM can be used to identify impact and consequences of changes. Findings are based on experiences from major oil and gas projects. Data is gathered from case projects in Kvaerner, a Norwegian EPC (engineering, procurement and construction) contractor. A new change management process is introduced to the construction industry, based on experiences from the oil and gas industry. This research shows that changes can be managed using a change control system (CSS). When a design change request is created in CCS, it is presented in a Change Board, and then considered by relevant disciplines. BIM are used to see the consequences and which disciplines are affected. The input will return to Change Board where the request is processed and either rejected or approved. If it is a client-driven change, the client will be added in the decision and presented for a cost and schedule impact. The paper assess how CCS combined with the utilization of BIM can reduce the impact of changes and manage internal or external changes in the design phase through efficient identification, evaluation, approval and implementation of changes.

**Keywords:** Building Information Modeling (BIM), change control system, change management process

## 1 Introduction

In the beginning of the design phase, everything change because there is a design development that by nature is a period where various concepts and alternative solutions are developed and evaluated. Before going into detail design, the conceptual development should be concluded and concept/design frozen. When construction starts, changes can be initiated by the contractor if it turns out that what is already designed and released on drawings are impossible to build. The client can come up with new requests or there can be changes to what the client already has requested.

Project teams often implement changes without fully understanding the potential impact on the cost and duration of the project, or the effect on contractual aspects or requirements as specified by the client. According to Isaac & Navon (2009) this is because the tools currently used for project planning and design are not able to evaluate the consequences of a specific change, before the plan and design are fully updated. As a result, deviations from the client objectives, caused by changes in the project, are often revealed late in the project or after its completion. The cost of rework in construction projects can be as high as 10–15% of the contract value. (Sun & Meng, 2009)

Previous research has pinpointed that project teams can be able to identify implications of a change as soon as it is proposed, using a change control tool. This will make it possible for the

engineers, and other stakeholders such as the client project manager and contractor, to know in advance if a change could cause the project to deviate from its original goals, or if special measures have to be implemented. In recent years, the use of building information modeling[1] (BIM) has become widespread. There is a potential of combining a change management system and BIM. This could allow the development of a tool that is able to link the different requirements and relationships between these. The tool could identify the impact of a proposed change of a certain requirement. (Isaac & Navon, 2008)

The research objective is to introduce a change management process to the construction industry, initially developed for use in major oil and gas offshore (and onshore) projects. This paper introduces a change control system (CCS), which is a tool that handles internal changes or changes to initial requirements from the client, in the design phase. The paper assesses how a 3D design environment[2], or BIM as the corresponding term is in the construction industry, can be used to identify impact and consequences of changes. There are two aspects related to a 3D design environment (hereafter called BIM) and change. The first is to use BIM as part of handling change requests in a change management process. The second is connected to milestones and the use of BIM related to frozen design.

The research is qualitative, conducted as case study research. Findings are based on experiences from project execution in major oil and gas projects through Kvaerner, one of Norway's largest EPC (Engineering, Procurement and Construction) contractors. The data has primarily been gathered from two case projects at Kvaerner. These offshore projects are delivery of topsides of production platforms in the North Sea, executed as EPC contracts, and one with engineering on a subcontract. An EPC contract in the oil and gas industry corresponds to a design-build contract in the construction industry, where the engineering and construction services are contracted by a single builder or contractor. Data has primarily been collected through documentation and interviews. Background information and detailed descriptions have been accessed through relevant company and project documentation. Interviews have been conducted with resources in key positions.

## 2 Background

### 2.1 Definition of change

According to Sun et al. (2006) and Sun et al. (2009), a change in construction projects refers to an alteration (or modification) to (pre-existing) conditions, assumptions or requirements. Being a project-based practice, the construction industry is normally disposed to a high degree of changes. Kvaerner has defined change as "any unplanned, out-of-sequence design development or change to execution method/sequence". (Kvaerner, 2012c) An unplanned development in design can refer to what is defined as an "unintended change", where changes take place unintentionally without intervention of managerial actions. They result from low work quality, poor work conditions or external scope changes. Change to execution method or sequence can refer to "managerial change", which is changes that take place on purpose, and are implemented by managerial decisions. (Motawa et al., 2007) Similarly, an unplanned development in design can also relate to "emergent changes", which arise spontaneously and are not anticipated or intended. Change to execution method or sequence can also refer to "anticipated changes" which are discovered during the project and before they actually occur. (Sun et al., 2006)

Sun et al. (2009) define five different causes of change; "project-related," "client-related", "design-related", "contractor-related" and "external factors". Poor communication between the key partners in a project is a main cause for design changes and rework, and forms the basis for project-related change. Client related changes are common, especially during the design stages, and are usually caused by variations in clients' expectations and requirements. Design-related changes are

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[1] Building Information Modeling (BIM) can be defined as a digital representation of physical and functional characteristics of a facility. It is a shared knowledge resource for information about a facility and forms a reliable basis for decisions during its life cycle – from concept to demolition (NBIMS, 2007)

[2] A 3D design environment refers to a multi-discipline and object based 3D design software integrated with a number of information systems that serves as the main source of information for engineering and construction. The main purpose is to improve the coordination and consistency between the disciplines responsible for the design in the project. (Kvaerner, 2012a)

based on design errors and exclusions and changes in client's requirements during a project, which often result in design modifications. There can be errors committed by the contractor or in equipment deliveries that causes changes in design and schedule delays. This, in addition to poor site management and supervision and difficulty coordinating subcontractors often cause contractor-related changes. External factors are often caused by climate conditions, site and ground conditions, or changes in government legislation and regulation.

Kvaerner (2012c) has defined 18 characteristics to what constitutes a change. These characteristics can be categorized using the different types of change defined by Sun et al. (2009) Nine of the characteristics have to do with contractual changes and modifications and requirements that are instructed by the client, which go beyond the basis for the contract (contractual agreements). This refers to "Client related" change. Three of these are related to design modifications, which include alterations to frozen design and proposal for design improvements. This corresponds to ""design-related" change. Three are related to modifications of work scope for the contractor, either as increased work or quantities from what is agreed on in contract, when work cannot be performed according to schedule. This refers to "contractor-related" changes. The last three are related to external conditions, including force majeure, changes to laws and regulations and changes to rates and norms. This corresponds with "external factors".

### 2.2 Internal vs. client initiated changes

According to Kvaerner (2012c) there are two forms of change in the design phase: one is a design development initiated by the project team and the other is a client initiated change. These two forms of change can result in eight potential outcomes, which are categorized in wanted or unwanted changes, and paid or unpaid changes. This is illustrated in the matrix in Table 1. Green, yellow and red indicates if a combination is desired, avoided if possible or should absolutely be avoided.

**Table 1:** Different forms and outcomes of change

| | | Paid (Client) | Unpaid (Client) |
|---|---|---|---|
| **Wanted** | (Client) | 1A: Client initiated | 3A: Client initiated |
| | (Project team) | 1B: Design development | 3B: Design development |
| **Unwanted** | (Client) | 2A: External | 4A: Design development |
| | (Project team) | 2B: Client initiated | 4B: Design development |

During the design phase, the client might initiate changes. If the cost and possible schedule impact (adjusted milestones and/or end date) are compensated for, these can be implemented. [1A] A design development is something that is usually linked to internal design processes. It may be the consequence of maturation and development of new (and improved) solutions initiated by the project team. If the change implies positive cost and schedule impact with fewer work hours and/or shorter execution time, and/or increased value for the client (and/or the end-users), the change can be accepted and paid for by the client. [1B] On rare occasions there might be external factors that influence the design process and cause a change that must be paid for by the client due to contractual obligations. [2A] There might be changes initiated by the client that have cost and schedule implications, where only the cost is compensated for. The consequences for the project team can be more critical if milestones are not reached than if the client pays for the change. If so, the change is not implemented. [2B] If the client initiate a change, but see the change as a design development and are not willing to compensate for the implications, it is a type of change that should be avoided by any means possible. [3A] If a change that is initiated from design development implies increased cost, and/or give marginal value for the client and/or end-users, the change can be rejected and thereby not implemented. [3B] The project team can initiate improvements during design development that have marginal cost and schedule implications. This is a type of change that is implemented but will not be covered by the client. [4A] Finally, design development may be the consequence of mistakes made by the engineers, omissions or lack of coordination between disciplines. That is an unwanted change the project team must cover and should avoid. [4B]

A design development that is unpaid is similar to what Sun & Meng (2009) has defined as "non-excusable causes", which are errors and omissions by the project team. A change that is initiated

from the client is similar to "compensable causes", which are usually related to requirement changes and client failures or delays. The project team can claim compensation from the client for any extra work resulted from changes by this type of causes. External factors that are beyond the control of the consultant and client are defined as "excusable causes".

In change management, the principles are the same for internal or client initiated changes. Experiences from case projects indicate that the accuracy is often not the same as with changes paid by the client. The focus is rather to implement it as soon as possible. When there are changes paid by the client, the project team calculates more and is more rigorous about what the consequences are. It is often a matter of productivity; how much is driven by client influences and how much is driven by mistakes and shortcomings of the project team.

## 3 Change management process

According to Sun et al. (2006) the objective of change management is to anticipate possible changes, identify changes that have already occurred, plan preventive impacts and coordinate changes across the entire project. The change management process in Kvaerner consists of four main activities; "General Project Execution Phase", "Change Board", "Change Handling/Solving" and "Requests to the Client". (AkerKvaerner, 2005) In the first, "General Project Execution Phase", the change management routines are established. Possible changes are identified. Requests for changes with contractual consequences (variation to the contract) are reviewed. A list of changes from engineering, called design change requests (DCR), and potential changes from the client, called variation orders (VO), are updated and prepared for presentation to a Change Board – a board that consists of a change manager and relevant delegates from engineering, planning, construction, subcontracting, procurement and contract/legal. In the second main activity, "Change Board", the Change Board will formally process changes. This includes approving or rejecting changes, requesting additional change documentation and issue a message to the client when further handling or approval is required. In "Change Handling/Solving" changes are formally communicated with the client. Cost and schedule estimates of approved changes are completed and CCS is updated. Change implementation is coordinated with all relevant parties. Project schedule is revised with approved changes when required. Handling of each change is prioritized, progress is monitored and relevant change documentation is updated in CCS. In the last main activity, "Requests to the Client", change order requests to the client, called variation order requests (VOR), are established and updated. VOR documentation is reviewed (with cost and schedule estimates) and sent to the client. Formal response from the client is received and instructions to the project team are issued. CCS is updated and progress of actions required to comply with client requirements is monitored. Changes and actions approved for each change are closed and CCS is updated.

The literature review has identified several attempts to create change management processes. A few of these are similar to Kvaerner's process. Ibbs et al. (2001) developed the project change management system (CMS). The system is based on five principles. In the first, "Promote a balanced change culture" the focus is to establish overall goals and objectives, roles and responsibility, and project philosophy related to change. "Recognize change" is about identifying potential changes, assess potential impacts, and log potential changes. These two principles are similar to the "General Project Execution Phase" main activity. "Evaluate change" is about defining priority, analyzing and defining impacts, and authorizing or stop/deny change. This corresponds with the "Change Board" main activity. "Implement change" is about implementing and receiving final change approval, communicating and documenting change decision, and monitor implementation. The scope of this principle corresponds with the third main activity "Change Handling/Solving", where internal changes are implemented. "Continuously improve from lessons learned" is to perform an evaluation, take corrective actions, compare to initial objectives and incorporate lessons learned.

Based on this research, Arain (2008) presented a similar change management system (CMS) with six principles; "Identify variations", "Recognize variation", "Diagnose the variation", "Implementing variation", "Implementing controls for variation" and "Learn from past experiences". Here, variation corresponds with change. The main difference is the fourth principle, "Implementing controls for variation", where the author introduces the process of selecting controls for variations, and documenting these. The first two principles correspond with the "General Project Execution Phase"

main activity. The third and fourth principle are somewhat similar to the "Change Board" and the "Change Handling/Solving" main activity, respectively.

Sun et al. (2006) developed a generic change management process model in four stages. "Start up" prepare a project team for effective change management. "Identification and evaluation" seek to identify potential changes and evaluate these to assist with the decision-making process. These two stages are similar to the "General Project Execution Phase" and part of "Change Board". In "Approval" the chosen change option needs to be approved by an appropriate member of the team, or by the client before it can be implemented. The internal decision process corresponds with part of the "Change Board" main activity. Part of the external decision process (towards the client) corresponds with "Requests to the Client". "Implementation and review" is a two-step process. When a change is approved, it needs to be communicated to all affected team members. If necessary, the schedule needs to be adjusted. This corresponds with parts of "Change handling/Solving" and "Requests to the Client". After the implementation, the project team needs to review and learn lessons from the change event.

Similarly, Motawa et al. (2007) introduced a change process model in four steps. The first step, "Start up", defines requirements for effective project management. "Identify and evaluate" identify changes (including causes, types and effects) and those affected or involved in decision process, and evaluate change options. These first two steps are similar to the "General Project Execution Phase" main activity. The second step also covers the principles of "Change Board". In "Approval and propagation", the client will review potential changes and either approve, reject or negotiate these. If approved, the project team implements changes. Minor changes or changes that does not need client approval are implemented. The internal decision process have similarities towards "Change Handling/Solving". The external decision process towards the client corresponds with "Requests to the Client". In "Post change", the focus is on finding a solution to potential disputes (if applicable).

The change management processes presented here are similar to Kvaerner's process, but with focus on different aspects. This is summarized in Table 2. The change management process in Kvaerner is used as a benchmark. The number of process steps is presented on the horizontal axis and the different sources are presented on the vertical axis. Green, yellow and red indicates high, medium and low degree of similarity of the process within each step in Kvaerner's change management process, compared to the different sources. The table illustrates that Motawa et al. (2007) has the highest degree of similarity, followed by Ibbs et al. (2001), Sun et al. (2006) and Arain (2008). It also illustrates that Kvaerner, unfortunately and in contrast to the other sources, does not have a corresponding main activity that focus on review of the process and learning from experiences.

**Table 2** Change management processes compared to Kvaerner

| Source | Step 1 | Step 2 | Step 3 | Step 4 | (Step 5) |
|---|---|---|---|---|---|
| **Kvaerner (2012)** | "General Project Execution Phase" | "Change Board" | "Change Handling/ Solving" | "Requests to the Client" | |
| **Ibbs et al. (2001)** | "Promote a balanced change culture", "Recognize change" | "Evaluate change" | "Implement change" | | "Continuously improve from lessons learned" |
| **Arain (2008)** | "Identifying variation", "Recognize variation" | "Diagnosis of variation" | "Implement variation" | | "Implement controlling strategies", "Learn from past experiences" |
| **Sun et al. (2006)** | "Start-up", "Identification and evaluation" | "Identification and evaluation", "Approval" | "Implement-ation and review" | "Approval", "Implement-ation and review" | "Implement-ation and review" |
| **Motawa et al. (2007)** | "Start up", "Identify and evaluate" | "Identify and evaluate" | "Approval and propagation" | "Approval and propagation" | "Post change" |

Change management is an overall work process that includes the proactive measures required to reduce the volume of changes, and to ensure that the cost, schedule and quality are under control, as well as the evaluation and implementation process. The sequence is defined as: Prevention – Identification – Filtration – Implementation. (AkerKvaerner, 2005) The first two parts of this sequence, "Prevention" and "Identification", is covered in the first main activity "General Project Execution Phase", where the routines are established (to prevent undesired handling of changes) and internal and external changes are identified. The third part of this sequence, "Filtration", is covered in the next main activity "Change Board", where the change requests are formally processed. The last part of this sequence, "Implementation" is covered in the last two main activities, "Change Handling" and "Requests to the Client". In "Change Handling", changes are communicated, implemented, and monitored. In "Requests to the Client", change requests that are approved from the client, and any additional change requirements from the client, are implemented and monitored. By following the four main activities in the change management process in Kvaerner, all four parts of the sequence will be covered.

## 4 Change control system

Kvaerner has developed a change control system (CCS), which is a system to store, control, report and follow up project changes and deviations. CCS is central in the change management process. A flowchart that visualizes the process from identification to implementation of a change has been developed (see Figure 1).
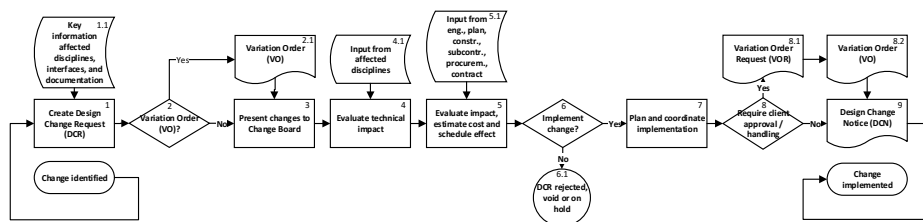


**Figure 1** Flow chart for handling changes using DCR in CCS

A change in design is identified with a design change request (DCR). An exception can be changes that occur in the early stage of the design (e.g. prior to the first milestone in the design phase). Here, it may not be necessary to make a DCR, if the change does not affect any other disciplines. A DCR looks at which disciplines are affected and what the time and cost consequences of each of the disciplines are and the sum of these. (AkerKvaerner, 2005) A DCR, is created in CCS with a name and an assigned number. The change can be identified through a Tag number (or line number or coordinates in space), which gives a direct routing to the relevant part of the BIM. [1] All relevant key information about the DCR (including affected disciplines) is stored as general information. The responsible persons for discipline input and relevant interfaces are configured. Relevant documents and drawings can be added to the change object. This includes excerpts of the BIM and other documentation that will further describe the change or its consequences. A reference to other change objects in CCS can also be made. [1.1] When the information to the change object is revised, the status of the DCR can be updated. Available statuses for the DCR are "Initiate" (created), "Recommend" (ready for recommendation), "Evaluate" (approved for evaluation), "Decide" (evaluation complete or ready for decision) and "Complete" (pending client approval, approved for implementation, rejected, void or on hold). (AkerSolutions, 2008)

The DCR is presented to Change Board, who meets on a regular basis, often weekly or bi-weekly. The engineer who has identified the change describes it for their discipline to the Change Board, who will follow up any changes or proposed changes. [3] The project manager can receive a message from the client containing potential changes [2] If so, a variation order (VO) is presented to the Change Board. [2.1] Should these change requests be implemented or not? The Change Board needs to see the consequences and who is affected. [4] All disciplines that are affected by each change are listed. The Change Board tries to limit it to those they believe have something to do with

the change, instead of sending it to everyone. According to Isaac & Navon (2009) it is difficult, if not impossible, for every team member in projects involving large teams to participate in every project review in order to answer questions concerning every proposed change.

For each change, the consequences for all relevant disciplines are described and reported back to Change Board. BIM can be used to identify consequences for the disciplines. The disciplines can give input to the change object, including plan, cost or weight information, engineering related data affected by the change, and the type of documents the change objects impacts. [4.1] When the disciplines have completed their input, the status is updated, and a notification mail to the responsible for the change object are sent, using CCS. Input to plan and cost for the various disciplines are summarized. The man-hours are summed up from the activity. The Change Board now has feedback on what the disciplines will do and the consequences, the need for rework and the hours needed. [5] The change can influence the project on several dimensions (e.g. construction, procurement, subcontracting, commissioning, etc.). It is therefore important to get input from all relevant delegates in the Change Board to evaluate the impacts of the change. One of the challenges is to appraise accumulative effects of having several changes. This will often have a schedule impact. [5.1] The Change Board now has the necessary information to decide if the change is to be implemented. [6] It may be that no matter how much the earnings (cost) are on a proposed change, the decision is not to proceed, because it has a schedule impact. There can be situations where not all consequences are identified, so that the DCR must be put on hold. Consequences if the change is not implemented shall be listed. In some cases, the DCR is for some reason no longer relevant and can be voided. [6.1]

If there is a decision to implement the change, it is planned and coordinated through the Change Board. [7] The change can be initiated as an internal change or a change from the client. Either way, a Design Change Notice (DCN) is created. [9] A DCN is an instruction for implementation, and is created on the basis of a DCR. The Change Board decides in practice if the change is something that is going to the client. [8] If so, a Variation Order Request (VOR) is created, which is a request to the client when a change has occurred. The argument is that the client has influenced the project team to make this change, and therefore must pay for the consequences. [8.1] A VOR can be created, and relevant data from the DCR is copied over to the VOR. The system will link the DCR and VOR together. If the VOR is accepted, a Variation Order (VO) is issued from the client, which are instructions issued from the client to perform a change. [8.2] This will result in a DCN (AkerSolutions, 2008) In a client-driven change, where a VO was received and presented to the Change Board, the client will be presented for cost and schedule impact of the proposed change. The project management can choose to earn more by implementing the proposed change. If there is a schedule impact and the consequence is that it is impossible to reach a milestone, it can be much more critical. The client can choose to implement the change, but then the relevant milestone must be adjusted and approved by the client.

There have been several attempts to create change management tools for the construction industry. Few of these are similar to Kvaerner's change control system (CCS), especially the use of a Change Board, and utilization of BIM to identify consequences of changes. One still worth mentioning is the change management toolkit (Sun et al., 2006). It consists of a standard procedure to identify, evaluate, approve and implement project changes, and a template for recording change events during a project. It also provides a tool to assess the likelihood of changes occurring and a workflow tool to assist in project rescheduling due to a change. The tool relies on extensive user inputs of project characteristics, which makes it difficult to use in practice. Another is the change control tool (CCT) developed by Isaac & Navon (2008), where change proposals are evaluated during the design and construction phases. The CCT is based on the building program and how that can serve as a framework for information management, with links to the client requirements and the building design. The CCT is designed to identify the implications of a proposed change by tracing the different relationships that exist between the requirements.

## 5 BIM and change management process

Changes in a project are many, but it is difficult, if not impossible, to pick up and register all. Changes are not identified because the engineers make a change on a frozen (finished) design, but tell no one about it. Then it becomes a clash afterwards that needs to be cleaned up. Costs are added up when changes have not been detected in time. When they are detected, it is often difficult to be

able to define all the consequences. If there is a client affected change, the cost and schedule consequences must be identified and the contract must be negotiated. Educating engineers more commercially can increase the accuracy. They will then know the consequences if they do not report a change, or if they make a change without noticing. The culture in the case projects at Kvaerner is relatively good in the sense that people come forward and speak about defects - even if it is in their own work. This also characterizes the Norwegian culture. BIM is an integrated part of the engineering toolbox. It is updated continuously. If there is a design change request (DCR), the BIM is used to assess if it is feasible and identify what the downstream consequences of the change are. An extract from the BIM, which shows what the change is all about and who is affected, is taken out so that the disciplines that receive it can identify the change visually in the model. The disciplines can go directly into the BIM, and see what they should do with their part of the design that is affected by this change.

Change can be perceived as an internal or external alteration in conditions for the contract, as described earlier, or alterations to frozen design/design milestones. (AkerKvaerner, 2005) In the design phase, the design is gradually frozen, once milestones are passed. The milestones describe which part of the design each of the disciplines shall be frozen to a certain time. All frozen parts should not be changed. When using BIM in the design phase, objects are gradually being frozen, as they reach the milestones and fulfill the requirements to update the object status accordingly. Once the design is frozen and some of that still must be changed, the changes must be managed, and then the design change process begins. Either one of the engineers find out that there is a need to change the frozen design, or the client need to change something that is frozen design. One of the challenges is to avoid changes due to "nice to have" design updates. This can be avoided by not requesting any design changes to what is sufficient or good enough. If there is a change request to something that is frozen, the relevant disciplines has to react by creating a DCR and not change anything without notifying the Change Board.

Engineers understand when the design is frozen, but being faithful to the decision of not changing frozen design is another matter. Engineers often acknowledge that things could have been done better as the project progresses. They are often tempted to make changes, especially if the client put their attention to it. There is a human element to this, that cannot be replaced with any change management system. It can be managed, to some extent, by focusing on commercial aspects. Similarly, the client often needs to learn what is frozen, and understand that when a milestone is reached in the design phase, there are parts of the design that is frozen, and should remain so. If there are changes to that, there will be consequences. But the client often likes to have the privilege to change anything anytime.

The relation between CCS and the use of BIM is based on what is frozen. Color codes can be added to the objects in the BIM software, which identify what is still being developed and what is frozen. Color codes relate to the status (maturity) to each object. CCS relate to BIM in the sense that if there is a change that touches objects with the red color code (frozen) it must be addressed. This helps the engineer to not change anything where it is frozen. On the other hand, if there is a different color code (still in development) it is not certain that there is a need to do anything at all, other than making the change.

## 6 Discussion

This paper has introduced the change management process in Kvaerner, and related it to research that describes similar processes for the construction industry. The scope of the first three steps in the change management process is, to a certain degree, similar. Kvaerner has divided implementation of changes in step three and four, where "Change Handling" covers change requests that are handled internally, and "Requests to the Client" are those that require client approval and feedback. Sun et al. (2006) and Motawa et al. (2007) covers both internal and client changes, but in the same step. Ibbs et al. (2001) and Arain (2008) does not mention client changes. All research sources include a last step, which focus on evaluating the process and identifying lessons learned, as prevention for later projects. This could preferably be added as a fifth step in the change management process in Kvaerner. This would give valuable input to the first step, "General Project Execution Phase", where the change management principles and routines for the project is established.

A change control system (CCS) is critical for handling change requests in the design phase in larger projects. The use of CCS follows the four main activities in the change management process. Using a design change request (DCR) as a starting point, internal and external changes are identified. The DCR contains a description of the change and identify any consequences for the discipline(s). BIM can be used to identify consequences of a change, which is often the difficult part in change handling. Relevant excerpts of the BIM can be attached to the DCR, in addition to relevant drawings and descriptions. Unlike other change management tools, Kvaerner has introduced the Change Board, that through a change manager and other relevant delegates, has a key role in deciding if a change is to be implemented or not. An important basis for decision is to identify consequences and relevant disciplines. In order to have an efficient process it is crucial that only those disciplines directly affected in a change is included. When the DCR is updated with input from the disciplines and status, the Change Board has the necessary information to decide if the change is to be implemented or sent to the client for consideration and approval. Either way, the result is a design change notice (DCN), which is an instruction for implementation of a DCR and is issued when the project is influenced. If the change is sent to the client, cost and schedule impact is identified. There are few similar systems developed for the construction industry. The change management toolkit (Sun et al., 2006) and the change control tool (CCT) developed by Isaac & Navon (2008) shows that the systems available have limitations. Despite this, having CCS that is based on many of the same principles, increase the relevance for use in the construction industry.

Color codes on objects in the BIM identify what is frozen. When the design is frozen and still must be changed, the changes must be managed. Before anything is changed, a DCR must be created, and the Change Board must be notified. Having a project team that is commercially astute in relation to change is important - whether it is client affected or internal change. The commercial, if it is internal change, is to correct it as soon as possible. Is it a client change, it should be identified as a client change and processed so that the client eventually will pay for it.

## 7 Conclusion

This paper has introduced a change management process in four steps, developed for use in major oil and gas projects. As presented in this paper, there are many similarities with other research that present similar processes in the construction industry. This makes the change management process in Kvaerner more relevant. The change control system (CCS) is close connected to and support the change management process. This paper has presented the principles of how the system works, from a design change request (DCR) is created to a decision of change implementation with a design change notice (DCN), and how it relates to the change management process. A central part of both is the Change Board, where a change manager and other relevant delegates use CCS to coordinate discipline input and manage change. A flowchart has been developed and the next step would be to define and set up a corresponding system for the construction industry. In the design phase, the design is gradually frozen, once milestones are passed. When the frozen design still needs to be changed, the changes must be managed. The use of BIM is essential and used to assess if the change is feasible and identify what the downstream consequences are. In addition, color codes are added to identify what is still being developed and what is frozen.

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Paper 6

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# Using BIM to follow up milestones in a project plan during the design phase

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## Abstract

Traditionally, progress in construction projects is done by manually reporting status on activities in a project plan, very often based on subjective evaluation. This increases the possibility to report different status than actual progress, especially in large and multidisciplinary construction projects with high complexity. Could the project plan be related to a building information model (BIM) and could project progress reported directly from the BIM lead to a more accurate, consistent and coordinated status?

This paper assesses how object status in the BIM can be related to milestones in a project plan. Findings are based on experiences from the oil and gas industry. Data is gathered from case projects in Kvaerner, a Norwegian EPC (engineering, procurement and construction) contractor. The paper examines how a project plan can be connected to a BIM, focusing on the benefits and possibilities of adding status to objects in the BIM and how project progress can be reported and visualized using BIM.

Research shows that project progress can be extracted directly from the BIM by introducing control objects, where objects in the BIM are assigned statuses that measures grade of completeness. Checklists are connected to control objects and define criteria that must be fulfilled to reach a correct quality level. Control objects are connected to activities and dated in the project plan. Status on activities can then be obtained and related to milestones, to see if the project is on schedule.

By defining control objects in the BIM and adding quality levels that measure status related to milestones, the control objects can be connected to activities in the project plan. Status on each activity related to each milestone can be obtained directly from the BIM. Instead of manual reporting, progress towards milestones in the project plan can be reported directly from the BIM.
*Keywords: building information modelling, project execution model, project planning, progress visualization, quality visualization.*

## 1 Introduction

When design moved from 2D to 3D, there was a need to get a thorough understanding of design progress, which was not very easy by looking directly into large and complex 3D models. Kvaerner, a Norwegian EPC contractor, started using a 3D design environment (a multidiscipline and object based 3D design software integrated with a number of information systems that serves as the main source of information for engineering and construction, where the main purpose is to improve the coordination and consistency between the disciplines responsible for the design in the project (Kvaerner [1])), corresponding to building information modeling (BIM) (a digital representation of physical and functional characteristics of a facility, and a shared knowledge resource for information about a facility, that forms a reliable basis for decisions during its life cycle – from concept to demolition (NBIMS [2])) in the construction industry. They began running collision controls, as part of interdisciplinary checks (IDC) in the design phase. It took a lot of time and resulted in tens of thousands of object collisions on a regular offshore production platform (topside). The process was gradually optimized, with a categorization of clashes into hard clashes (critical clashes between objects trying to occupy the same space) and soft clashes (clashes between the obstruction volumes provided around objects for access or clearance, and not the physical object). But did it say anything about the quality of the 3D design environment (hereafter called BIM)?

Kvaerner started with the objects in the BIM and looked at how they were able to harvest status on objects that had reached a measurable level of quality. Status definitions were defined for use on objects in the BIM. When the designer had completed a defined work, the objects were given relevant status. A checklist with a number of control questions were prepared for each discipline, which focused on execution on own work and interfaces towards adjacent disciplines. When the control questions were fulfilled, they were signed off in the checklist and a higher status was achieved. Several status levels were established. Eventually Kvaerner were able to extract statuses directly from the BIM, which formed the basis for the connection towards the milestones and eventually the project plan.

In research on project progress with the use of BIM, there has been very little focus on the use of object status, especially in the design phase. Sacks *et al.* [3] developed a BIM-enabled system to support production planning and day-to-day production control on construction sites. Common for this and similar solutions, is visualization of project and work status, by color-coding of objects. BIM is ideal for visualizing process and is used to show information that is specifically filtered for the viewer. This includes the ability to query visible objects for their relationships with work packages and their changing status through time. Similarly, Chen and Luo [4] has defined how the BIM describes quality status in construction with different color codes. The color codes are grouped in two; before or after inspection is performed. When the relevant part of the BIM is accepted (passed), it will be marked with yellow color code. If the part of the BIM fails an

inspection, it will be marked red. A nonconformance report that states the violation of codes that fail to deliver the consistency of design intent and construction results will be issued for corrective action.

The main focus in research on BIM and progress is related to the construction phase and the 4D concept, where objects are linked to construction schedules, where time represents the fourth dimension. Traditionally, a 3D model and a project schedule, which are developed separately, have been combined into a 4D model. A schedule simulator is utilized to link the objects with the related scheduling activities. The resulting 4D model displays the construction sequence by showing consecutive objects as a progression over the time-span of the project (Wang *et al.* [5]). The 4D concept has been adopted in industry and several commercial applications are available for 4D construction planning (Sacks *et al.* [6]).

The focus of this paper is to assess how BIM can be used to follow up milestones in a project plan in the design phase. The paper is divided into two parts. The first part of the paper introduces control objects and the use of quality levels in BIM, and how status definitions can define quality of a design. The second part focuses on how control objects in the BIM can be related to milestones in the design phase, how the milestones in the design phase are related to the project plan, and how BIM can be used to follow up activities in the project plan.

The research is qualitative, conducted as case study research. Findings are based on experiences from project execution in major oil and gas projects through Kvaerner, one of Norway's largest EPC contractors. The data has primarily been gathered from two case projects at Kvaerner. These offshore projects are delivery of offshore production platforms (topsides) in the North Sea, executed as EPC contracts, and one with engineering on a subcontract. An EPC contract in the oil and gas industry corresponds to a design-build contract in the construction industry, where the engineering and construction services are contracted by a single builder or contractor. Data has primarily been collected through relevant company and project documentation and interviews with resources in key positions. The aim is to identify findings that can be adapted to the construction industry. According to Mejlænder-Larsen [7] the more similar the oil and gas industry and construction industry are related to project execution, and more specifically on variables related to BIM, the more relevant the findings from the oil and gas industry will be towards the construction industry.

## 2 BIM and design quality

### 2.1 Control objects and quality levels

A design deliverable may be divided into detailed sets of information linked to suitable control objects for each discipline. A control object consists of either one or several similar objects or objects that are grouped together with other related objects. All control objects will achieve the same quality level in the design phase (and in subsequent phases). The grade of completeness for a control object is described by status definitions. The status numbering, name and description are

common for all control objects. Quality level is the degree of completion an activity or deliverable have at a given time, and how far each discipline has come, or how much they have done. Quality level describes what should be the quality of a given control object from creation to completion, divided in certain steps. Each quality level shall be achieved prior to or at certain milestones. The quality level descriptions refer to status for control objects (AkerSolutions [8]). Status for each control object is illustrated with a color code, so that the BIM can display the quality level directly, using color codes on each object. In design, the main quality levels are S1 "Preliminary", S2 "Release for verification", and S3 "Frozen". See Table 1 for all status definitions in the design phase.

Table 1:    Status definitions used in the design phase (AkerSolutions [8]).

| Status | Name | Definition | Color |
|--------|------|------------|-------|
| S1 | Preliminary | Control object registered with preliminary/ estimated information. | |
| S2 | Released for verification/IDC | Control object released for verification/ IDC. Necessary information required for the verification/IDC included. | |
| S3 | Frozen | Verification/IDC comments implemented. Interface towards other control objects and other disciplines frozen. | |
| S4 | Detail design completed | Detail design of control object completed and approved for construction. Detailing shall not affect interfaces to other disciplines and control objects. | |

The connection between control objects, quality levels and status levels are illustrated in Figure 1. The illustration shows a simple concrete structure that consists of a base slab with four columns in each corner and a top slab that rests on the columns. The entire concrete structure can be seen as one system, where all objects are mutually dependent of each other. The control object is the concrete structure. The quality level of the control object is defined using status definitions (S1–S4). To fulfill a desired quality level, in this case S3, all objects must have achieved the same status level (S3). Each status level is displayed with unique color codes. Here, all objects have status S3, except column 1, which have status S2. If there are minor adjustments needed before the column can be lifted to status S3, the control object can still obtain quality level S3, but with column 1 on Hold. This means that it will be put on a punch list with outstanding issues that must be solved.

The use of status can be applied broadly. If four status levels on quality (and progress) are defined, then these can be applied in construction projects. It is important that criteria for how far the design should have come at the different status levels (S1–S4), and that they are defined relative to something that brings the work to completion.
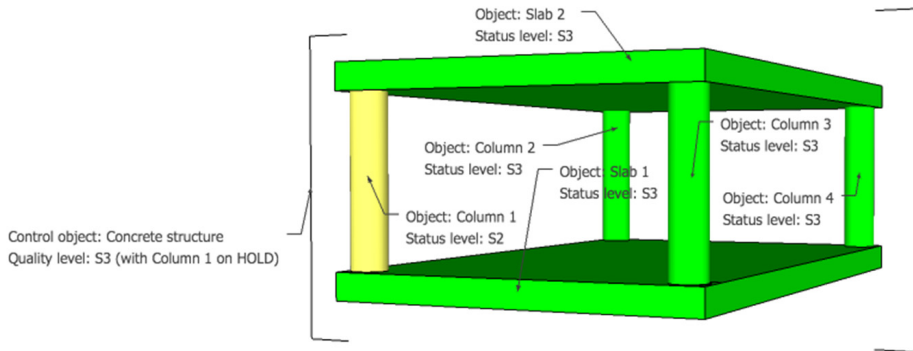
Figure 1:    Illustration of a control object with quality level and status levels.

The status definitions (S1–S4) define the grade of completeness or maturity for a control object at the various milestones. Similarly, Sacks *et al.* [3] define 'maturity' to be a measure of the state of readiness of a work package or a task. The maturity index is displayed using color-coded symbols on task icons. Unresolved preconditions may prevent execution of the work correctly, on time and with the expected level of resource consumption.

With each control object there is a checklist that defines the requirements that must be achieved at the different quality levels. It works in the sense that when a discipline has created a design, the discipline goes through a checklist with a number of control questions for each control object. In order to demonstrate that the quality level has a certain status, (for example S3, "Frozen") all control questions shall be checked off. The discipline engineer is responsible for this. What is not done must be transferred to a punch list, so that it can be taken into account in the continuation of the work. The checklists and quality levels related to the control objects are in Kvaerner is implemented in their BIM software (AVEVA PDMS [9]). When all control questions in the checklist connected to each control object are fulfilled and checked off by a discipline, a higher quality level is achieved and status with color codes is set by the BIM software. Kvaerner has over the years developed an increasing number of control objects where the corresponding checklists are related to milestones and subsequently progress in the project plan. The reason is to try to move away from personal estimates, sometimes guesstimates, on how far each discipline has come (for example 30% complete).

Status is both quality and quantity. If a discipline have gone through the relevant checklists and fulfilled all criteria in those, and for instance achieve quality level S4 ("Detail design completed"), then relevant control objects have a quality that enables the discipline to start producing drawings for construction. At the same time, the achieved quality level is a goal, because the design will have a given number of control objects in status S4. If not all control objects are on status S4, the relevant discipline is behind schedule. If all control objects have status S4 the discipline is on schedule, and satisfy both quality and quantity.

Research shows that quality in the BIM can be seen through status on the objects in the model. According to Sacks *et al.* [6] visualization of process status

is needed and should be displayed in a manner that can be readily understood by all, regardless of their technical knowledge. The focus has primarily been on developing a system for the construction phase, and not the design phase. The authors have defined work status icons that are shown for each location in a 3D model view for construction. This representation provides the status, the duration for which the current status has been valid, and the expected remaining work duration, where relevant.

A topside facility on a production platform often consists of up to 100,000 objects. Kvaerner cannot define control objects to follow up all of these, but must focus on the most central ones, being essential for keeping control of the project. First, Kvaerner focus on objects that are technically feasible to achieve status from. Because of the size and complexity of a topside, there will be objects that are not modeled in detail. An example is a valve, where the bolts used for fastening are not modeled, but are defined in the specification attached to the valve. Second, Kvaerner focus on objects that have several other objects connected to them, which means that the status on one object implies the same status on connected objects. An example is if a complete (frozen) pipe is located, it will assume that the steel supporting the pipe is complete. With this as a basis, Kvaerner active measures status on a minimum of 30% and up to 50% of all objects in the design phase from defined control objects in the BIM. The rest is measured manually on each activity in the project plan, where the discipline leaders set the status for each of the relevant disciplines.

## 3  BIM and design progress

### 3.1  Project execution model and milestones

The initial design phase in Kvaerner is called "System Definition" and consists of three stages (AkerSolutions [10]). The content and scope of these three stages are similar to the three stages in the design phase for the construction industry, as defined by RIBA [11]. This increases the relevance towards the construction industry. See Figure 2 for a comparison of the project stages and milestones in the two industries. In the first stage, both have focus on basis requirements for the design. The objective of stage 2A "System Design", with milestone M2A, is to identify and confirm all design basis requirements. In stage 2 "Concept design", the initial concept design is produced in line with the requirements. The second stage focuses on further development of the concept design. The objective of stage 2B "System Design and Layout Development", with milestone M2B, is to further develop the design and make sure that the overall layout is frozen. In stage 3, "Developed design", the concept design is further developed and the design work of the core designers is progressed. In the third stage, the design is finalized and frozen. The objective of stage 2C "Global Design", with milestone M2C, is to further develop the system and area design to a stage where all interfaces and the system design shall be frozen. In stage 4, "Technical design", the architectural, building services and structural engineering designs are further refined to provide technical definition of the project and the design work is developed and concluded.
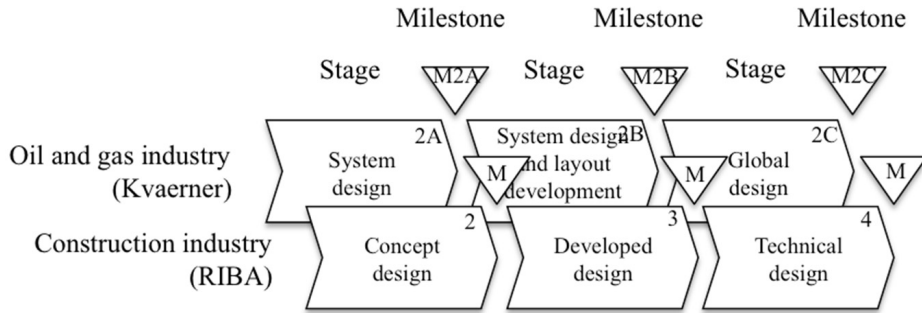
Figure 2:   Comparison of project stages and milestones in the design phase.

Kvaerner has developed a project execution model (PEM), which defines what should be done, when it should be done, to what quality and at what status. The objective of a PEM is to secure predictability in project execution using a standard methodology well known to the project team. It reflects a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones to ensure predictable project execution (Kvaerner [12]).

All disciplines should know at any given time how far they are expected to have come. Knowledge of where the disciplines are is equally valuable whether they are on, ahead of or behind the milestone. If the disciplines do not measure in proportion to the status line, they in fact do not know if they have a problem and how to deal with the problem ahead. It is only when the milestone is set and is measured against it is possible to know. Experiences from the case projects show that to a milestone in the design phase, disciplines can be ahead and disciplines can be behind with their design. If a discipline has come too short it is a problem, and if a discipline has come too far, it may also be a problem. The main challenge is to take care of those behind and decide what to do with them in the continuation of the project. When the disciplines that have been behind catches up, they can influence those already finished. Much of what is done must then be redone, because the disciplines already finished have based their design on unfinished design basis, and can have made assumptions that are not correct.

The PEM controls what is the optimum picture at any given time in project progress so that all disciplines are in balance with each other. The more balance on the status line, the more likelihood for fewer design changes. The entire structure of the PEM is based on the simple reasoning that it should not be random how far each discipline has come on the various inputs on a given milestone. This is described through milestone requirements. Audits are conducted on milestones, where punch lists on what may not have been finished to the relevant milestone are developed. It will then be taken into account in the planning process in the continuation of the design, to be able to add it into future plans and to the resource picture.

The client will have contractual milestones. The milestones defined in PEM should be distributed the best way possible in the project, so that it becomes consistency between when the client claims something should be done and when

the PEM says that it should be done. Adding milestones defined in PEM as parallel as possible with the contract milestones to the client, will avoid communicating a different message to the project team in every project. Kvaerner will always find that the client put various milestones into the contract that the client wants to measure Kvaerner on, and can add penalty or bonus to the milestones. There is also a project deadline with daily fines. Any discrepancies to each milestone must be dealt with. A punch list must be developed, so that the project plan can be considered and adjusted in relation to that. The knowledge of what have not been done is as important as the knowledge of what have been done.

## 3.2  Milestones and project plan

A project plan is created with a number of activities that should be measured on the status line related to a milestone. The activities describe control objects with relevant quality levels. Measuring begins with what is planned (forecast) status compared to actual status, to see how it complies. This is handled in regularly (weekly) meetings in Kvaerner. If the control objects should have been on quality level S4 (for example) on a given date (for milestone M2C all should be on status S4), the relevant disciplines (piping, electrical, etc.) can be chosen to see where they are behind, where they are on, and where they are ahead.

There are approximately 30,000 activities in the project plan needed to build a topside. Gradually, through experience, Kvaerner have found out what the content should be, how far the disciplines should have come and what quality the deliveries should have, when the milestones are reached. The advantage of the planning system is that there are many activities that are related in a logical line, and that helps to analyze the consequences when the milestones are not reached.

All activities that will be completed are marked against each milestone in the design phase. It will then be possible to follow how far the disciplines have come. The focus is not on the activities that go through, but on those to be completed. A report that shows how each activity relates to project progress can be created. This is done on a regular (weekly) basis in the case projects.

Progress planning always starts on the date of completion and goes backwards. And so the milestones are drawn up. This methodology ensures that what shall be delivered at the completion date receive sufficient focus. PEM is not a project plan, but can reflect the plan whereas all activities in the project plan are sorted with an identifier towards milestone and quality level. The goal is to create a project plan that enables a maximum degree of harvesting of status from the BIM. Each control object is linked to the project plan through the milestones. Kvaerner has developed planning checklists that define what should be achieved by the planning system to each milestone, how many activities there are, if the activities are linked logically, if it is broken down in a way consistent with the established WBS structure etc. When the quality levels of all control objects are exported from the BIM, they can be linked to the activities in a project planning and reporting application, which in Kvaerner is Safran Project (Safran [13]).

## 4   Conclusion

This paper has introduced control objects and how the quality levels on these are defined using different status definitions. Correct quality levels on each control object for each discipline to each milestone in the design phase can be reached by fulfilling relevant checklists. The maturity and quality of the BIM can then be visualized, through status color codes on each control object for all relevant disciplines. The control objects in the BIM can be connected to the project plan through milestones. Activities for each discipline in the project plan describe the quality on control objects that must be reached to each of the milestones in the design phase. This can be expressed through quality levels on the control objects. This makes it possible to aggregate status of activities (related to a milestone) directly from the BIM, through quality levels on relevant control objects.

The common denominator for the connection between plan and BIM are milestones. All milestones and control objects with quality levels are dated in the planning system. All activities in the project plan are linked to the milestones. The quality level on each control object (for each discipline) on a given milestone can visualize whether the project (through disciplines) is ahead of, on or behind schedule. Instead of manually reporting, progress towards milestones in the project plan can be reported directly from the BIM.

This paper has described how we can report progress towards milestones in the project plan, as defined in a project execution model (PEM), directly from a 3D design environment (BIM), based on experiences from case projects at Kvaerner. According to Mejlænder-Larsen [7] the oil and gas industry and construction industry have a high degree of similarity related to project execution, and more specifically on PEM and BIM, which makes the findings in Kvaerner relevant to adapt towards the construction industry. The focus for further research will be to discuss the findings theoretically and to develop concepts (models and frameworks) to be able to use the findings identified in this paper in the construction industry.

## Acknowledgements

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## Paper 7

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# Improving Transition from Engineering to Construction Using a Project Execution Model and BIM

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## Abstract

Usually engineering takes place during a given time period, followed by construction. Shorter time from project start-up to delivery gives higher parallelism between project phases. Construction pushed in parallel with engineering places greater demands on the actors. Parallelism calls for increased interaction between engineering and construction. This paper assesses how transition from engineering to construction can be improved with the use of a project execution model (PEM) and utilization of building information models (BIM). Findings are presented in three interdependent dimensions; process, people and technology. Research is based on case studies of major oil and gas projects, where data is gathered through Kvaerner, a Norwegian EPC (engineering, procurement and construction) contractor. Primary focus is on EPC contracts, where engineering and procurement is subcontracted, which corresponds to design-build contracts in the construction industry. The EPC contractor will build in a sequence that is cost effective for them, while the engineering subcontractor prefers to think in a totality until engineering is finished. Parallelism challenge this. To improve transition, it is important with a correlation between how one conducts engineering and how one plan to build. How can deliveries from the engineering subcontractor be produced in an order that fits into the desired build sequence to the contractor? The paper portrays how an alternative contract model is used, how common drivers are established and how the use of a 3D design environment, which corresponds to BIM in the construction industry, is rearranged to support this. "Right the first time" is when a certain quality level is achieved to a certain point in time. Using a PEM supports this by defining requirements on each milestone that must be achieved to reach the desired quality level. If some disciplines are behind and some ahead of a milestone, it will not be "right the first time". How can the engineering subcontractor satisfy milestone requirements to the contractor and deliver "right the first time"? The paper shows how the engineering subcontractor, with certain additions and adjustments to their milestones, can support this. The integrated design and delivery solutions (IDDS) approach relate the findings towards the construction industry.

**Keywords:** building information model, build sequence, joint venture, milestone requirements, project execution model

# 1. Introduction

In current practice, engineering and construction phases are not well integrated (Luth et al., 2013), and usually engineering takes place at given period of time, followed by construction. In offshore projects, executed at EPC (engineering, procurement and construction) contracts, construction is often pushed in parallel with engineering. EPC contracts corresponds to design-build contracts in the construction industry, where the engineering and construction are contracted by a single contractor. Influence and inclusion of contractors in engineering in design-build contracts is important since contractors can receive deliveries based on their expertise in buildings solutions (Berard and Karlshoej, 2012). This involves grouping activities into work packages so that construction can start before the design phase is complete (Bogus et al., 2011). To improve transition, it is important that there is a correlation between how one conducts engineering and how one plan to build. When working in parallel, the contractor starts at a certain place and build, and that is the place engineering should have drawings and materials first. The paper assesses how deliveries from the engineering subcontractor can be produced in an order that fits into the desired build sequence to the contractor. This can be fulfilled using a project execution model[1] (PEM), an alternative contract model, common drivers for the project team, together with an altered structure of a 3D design environment[2]. A 3D design environment corresponds to a building information model[3] (BIM) in the construction industry. The paper investigates how the engineering subcontractor can satisfy the milestone requirements to the contractor and deliver "right the first time". The engineering subcontractor can accomplish this by adjusting their milestone requirements in the design phase. Primary focus is on EPC contracts, where engineering and procurement is subcontracted.

The findings in this paper are divided into three interdependent dimensions; process, people and technology. Process, people and technology are identified as core organizational issues (Sacks et al., 2010) or categories used to classify challenges and benefits in an integrated design process (Rekola et al., 2010). To succeed requires a holistic approach, where all three dimensions are mutual dependent of each other. The first part, process, looks closer at parallelism in EPC contracts and how an engineering subcontractor can support this by adapting to a desired build sequence to the EPC contractor. This requires "right the first time" deliveries, with right information at the right time, and milestone coordination between the engineering subcontractor and EPC contractor. To accomplish this requires focus on the second dimension, people, which identifies common incentives and drivers. This includes the possibilities of establishing a joint

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[1] A project execution model (PEM) reflects a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones. The objective of a PEM is to secure predictability in project execution using a standard methodology well known to the team Kvaerner, 2012b).

[2] A 3D design environment refers to a multi-discipline and object based 3D design integrated with a number of information systems that serves as the main source of information for engineering and construction (Kvaerner, 2012a).

[3] A building information model (BIM) can be defined as a digital representation of physical and functional characteristics of a facility, and a shared knowledge resource for information about a facility that forms a reliable basis for decisions during its life cycle (NBIMS, 2007) .

venture between the engineering subcontractor and EPC contractor, identify drivers to secure alignment to common goals and mobilize new project teams. This also requires focus on the last dimension, technology, which investigates how a 3D design environment (hereafter called BIM) can be utilized to support a desired build sequence to the EPC contractor.

The integrated design and delivery solutions (IDDS) approach (Owen et al., 2009) is applied to discuss whether the findings on process, people and technology are relevant towards the construction industry. The IDDS approach is used to elucidate that these findings are factors that should support performance improvement in the construction industry. The construction industry is under pressure to reduce project delivery times and costs despite increased complexities in today's projects (Jaafari, 1997, Bogus et al., 2005). The approach challenges traditional industry structures and contractual processes, which corresponds with the research presented in this paper.

## 2. Research method

The research is qualitative and based on case studies. Data is gathered from three case projects in the oil and gas industry through Kvaerner, a Norwegian EPC (engineering, procurement, construction) contractor, executed as EPC contracts. The primary case project has been the topside for one of four platforms of the Johan Sverdrup field on the Norwegian continental shelf, which started detailed engineering in 2015. Secondary case projects have been the topsides for the Edvard Grieg platform and the Eldfisk platform, delivered in 2014. All three consists of a combined living quarter and utility module. Data collection has been conducted by the author through interviews, supplemented with relevant company and project documentation. Data has primarily been gathered from 8 semi-structured interviews, with the use of interview guides, from March 2013 to October 2015. Four of the interviews, had main focus on transition between engineering and construction, three on the use of PEM, and the last on the use of BIM. The average length of the interviews has been 1 hour 47 minutes. Each interview has been conducted with one to two interviewees in key positions in the cases, including Project Manager, Information Manager (responsible for all aspects of information handling in the project), and Head of PEM. The stepwise-deductive-inductive (SDI) method (Tjora, 2012) has been applied to analyze the collected data. The principle of this method is to work stepwise from data to concepts or theories (inductive) and verify these theoretically to the more empirically (deductive). The collected data has been transcribed and used to develop "empiric-close" coding that reflects the contents of the text. The codes have been sorted into larger groups of themes, called categories, and used as a basis to develop concepts that capture central characteristics of observations and findings. This is similar to what Halkier (2011) has described as "category zooming", as a way to generalize qualitative data. This is a three-step process, from coding and categorizing, through tracing of systematic relationships between categories and finally aiming for conceptualizing.

# 3. Process

## 3.1 Parallelism and build sequence

According to Lee et al. (2005), parallelism, or concurrent engineering and construction, is gaining popularity due to the increased demand for shorter time frame of projects. In Kvaerner, parallelism gives greater challenges than if construction can be deferred until after the engineering has completed. The extent of the challenge depends on client's requirements to the contractor. The client sets the scene in terms of how complex the process becomes, by setting the time frame from the contract is signed to delivery date. Longer time frame gives more predictability between the phases. Shorter time frame gives a higher degree of parallelism between the phases. The more parallelism there is in a project, the greater demands are put on the participants in that they know what the sequence and the quality requirements of the project is. This is similar to what Succar (2009) has defined as "BIM stage 2", where engineering and construction is in parallel, and is driven by construction providing design-related services, and engineering increasingly adding construction and procurement information into their BIM. Integration of engineering and construction is not new, and similar terms and techniques have been used to respond to the time and cost pressures in projects (Jaafari, 1997). Parallelism is similar to concurrent engineering (CE), where the aim is to reduce the total delivery time and cost of a project by overlapping activities that are normally performed in a sequence (Bogus et al., 2011). In the last decade, the concept of integrated concurrent engineering (ICE) have also been introduced, where the focus is to "speed up the process by increasing task parallelism and reducing response latency and lag, which decelerate legacy multi-disciplinary construction engineering processes" (Alhava et al., 2015).

Engineering influences all project phases. In Kvaerner's PEM, the design phase consists of three stages with corresponding milestones (M2A, M2B and M2C). During these stages, the BIM is developed to a quality level where the design and all interfaces (between disciplines) are frozen. When the last milestone, M2C ("Global design complete"), is reached, the the BIM should have reached a defined quality level so that the engineering subcontractor can start issuing drawings, and Kvaerner can start construction (see principle in Figure 1).
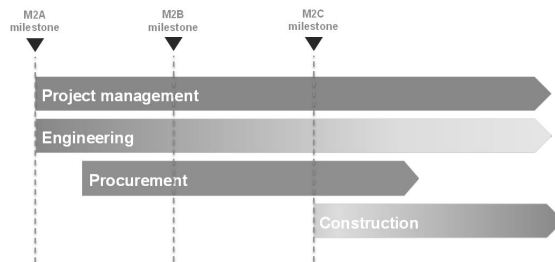


*Figure 1 Parallelism between E, P and C (Kvaerner, 2013)*

With parallelism in EPC contracts, it is important to be aligned in the sense that there is a correlation between how one conducts engineering and how one plans to build. A common challenge is that Kvaerner will build in a sequence, which is cost effective for them, while the

engineering subcontractor would prefer to think in a totality until design is complete. In order to get drawings and materials at the right time when construction is pushed in parallel with engineering, Kvaerner has made a build sequence that engineering and procurement must know of, because they will need to deliver according to it. The ambition to Kvaerner is that engineering is conducted in an order that fits into the build sequence that gives the fewest possible hours in the workshop. The dilemma is that the engineering subcontractor do not know Kvaerner's build sequence, and Kvaerner does not know how the engineering subcontractor conducts their engineering deliveries. Kvaerner's PEM can describe how it is done and at what status deliveries should be on each milestone, but Kvaerner has to tell the engineering subcontractor what they need to deliver. Kvaerner has therefore spent a lot of time with the engineering subcontractor to explain how Kvaerner's build sequence is and what they require of engineering deliveries, including drawings, materials as well as equipment components, to support this, so that the engineering subcontractor can adapt its engineering deliveries to Kvaerner's build sequence.

## 3.2 "Right the first time"

According to Kvaerner, the various input factors must have come to a certain level in quality and progress, on a given milestone. If someone goes too far and others too short, it will not be "right the first time". In the design phase, all disciplines should know at any given point in time how far they should have come with their design. If a discipline has come too short and not fulfilled the requirements at a milestone, they can influence the others when they are finished. If a discipline has gone too far, the discipline might need to redo much of what is done while the other catches up, because the discipline have made assumptions that are not met. Similarly, Lee et al. (2005) has stated that successor activities that have to start without complete information from predecessor activities, may lead to a chain of wrong decisions in other related activities. Whoever succeeds to optimize the process best will be the cheapest and fastest.

"Right the first time" is doing it right the first time and not having to do it over again, and is something Kvaerner strive for. Kvaerner's PEM supports "right the first time" by defining milestone requirements and associated discipline checklists to all stages in each project phase. In each project, the client will have contractual milestones. The milestones defined by Kvaerner in their PEM are distributed as parallel as possible with the contractual milestones to the client, so that it is consistency between these. It is also to avoid communicating a different message to the project team in every project. When the final milestone in the design phase, M2C, is reached, the objects in the BIM are at a quality level that one can begin issuing drawings for construction. The design is frozen, and should by definition not be changed. At the M2C milestone, engineering should have fulfilled the milestone requirements to satisfy Kvaerner's build sequence, so that Kvaerner safely can start construction. This is similar to what Schade et al. (2011) identifies as a quality gate, where design maturity is synchronized and evaluated, and reflects the detailing of the design, in a concurrent engineering approach. When Kvaerner conducts projects with engineering and procurement on a subcontract, both parties has their own PEM. Like Kvaerner, the engineering subcontractor has organized their work in a way where they have milestone requirements and associated checklists (for each discipline). To make sure the engineering subcontractor has come as far as required on the last milestone to start deliveries to construction,

their milestone is checked against Kvaerner's milestone (M2C). The methodology is based on the fact that the requirements that Kvaerner has made for the last milestone in the design phase (M2C), in terms of what the disciplines should deliver and to what quality level, is adapted to Kvaerner's build sequence. The requirements for each discipline at the M2C milestone and the corresponding milestone to the engineering subcontractor is compared through a GAP analysis, to see if the engineering subcontractor are close to fulfilling the requirements at the M2C milestone. They identify the gaps between the two milestones, and go through the checklists for all relevant disciplines, and look at where they need to increase the requirements. Kvaerner wants the engineering subcontractor to use their own PEM, but with certain milestone additions and adjustments, to satisfy Kvaerner's build sequence. The main reason for this is that the barriers for adapting new milestone requirements are lower when using a familiar PEM. If the engineering subcontractor meet the requirements in the last milestone in the design phase, it is very likely that Kvaerner's build sequence can be used.

# 4. People

How do you merge engineering and procurement with construction? According to Kvaerner, when working as an EPC contractor with control over both engineering, procurement and construction, rational considerations can be made in terms of how spending and earnings should be, in order to optimize the bottom line. It is the company that determines the optimal sequence and the desired order of deliveries from engineering, procurement and construction in each project. When there are two separate companies, the interests of one may not always easy favored by the other because of different economic drivers. With engineering and procurement on a subcontract, there can be different contract models between the EPC contractor and the engineering subcontractor. As soon as these two parties have a contract regime that exist between them, the engineering subcontractor will work according to their drivers - that often do not correspond with the drivers the EPC contractor has. It is typically the contractual terms to the engineering subcontractor that drives them. If they have day penalties on deliveries, or reduced compensation if they spend too many hours, they work according to that. But then it might be that they are not as concerned about whether the quality of the deliveries is 100%. According to Jaafari (1997) each actor in a project tends to manage their own scope in a way that minimizes their own exposure to risks and maximizes their gain, which may lead to divergence of objectives of the parties from project objectives.

According to Kvaerner, the engineering subcontractor can work according to a fixed price or paid per hour with a profit, in a subcontract. They must take responsibility for their deliveries - either through performance milestones or through milestones with day penalties. If drawing quality is too poor, drawings must be recalled and updated on their own expense. A subcontract can work out if the contractor requires defined drawing deliveries, and can set fines or bonuses on deadlines. They can probably agree on a better order of the drawings (in relation to the build sequence). Kvaerner emphasizes that it is important that the contractor and the engineering subcontractor have common drivers related to engineering deliverables. This leads to another variant, a joint venture, where the two parties share a common bottom line. According to Owen et al. (2010), contractors can operate integrated on individual projects, or establish temporary joint ventures, to

provide cost, time and delivered quality benefits through more integrated processes. The understanding throughout joint venture is that if the engineering subcontractor (or contractor) do not manage to deliver, there will be no bottom line to share. For Kvaerner this is the most effective, because then they do not need to be as aggressive in trying to follow up the engineering subcontractor as in a traditional subcontract. Then they are partners, both knows what applies, and have the same drivers. In the agreement Kvaerner has made with the engineering subcontractor in the primary case project, the parties have established a joint venture for a joint EPC, where they are "joint and several" responsible. This means in practice that if one part is not performing, it has a consequence for the other. If one part goes bankrupt, then the other part must complete the work the other should have done. They are mutually dependent of both parties performing and they share profits on the bottom line in a percentage distribution. It is a model that better prepare for an improved transition between engineering and construction, because they have a common driver. The engineering subcontractor only get their expenses covered through invoicing, and only get the profits from what is left of the cash balance in the end. This means that the engineers at the engineering subcontractor should be motivated to perform and deliver as planned. If not, they can go from sharing profits to covering deficits afterwards.

It might be that despite establishing a joint venture, the motives for the two partners can be different. It may be so that the engineering subcontractor that works for Kvaerner can lose more on another contract than the contract in question, if they do not make a greater effort. They might choose to withdraw personnel and move over to the project that has greater challenges or that has a greater risk associated with it. The engineering subcontractor that works for Kvaerner can also work for several other construction yards, which has no build sequence, not the same requirements to a build sequence, or does not have the same requirements to a PEM that Kvaerner has, which can make the adoption more challenging to accomplish. In this case they must reach down to every discipline and get them to understand that now they need to satisfy another build sequence, which is another way to deliver on. Kvaerner point out that there are mechanisms that can support this. They can both select key personnel. Both parties must then approve the competence of key personnel that the other deploy into the project. By exchanging CVs on key personnel, they both can be assured that they are putting on experienced and competent personnel, on equal terms. There will be penalties if any of the personnel are withdrawn from the project. This will prevent the ability to juggle too much with personnel and competence. Both parties should feel equally safe for doing the best they can. A key to influence and train engineers is the use of a PEM with common milestone requirements, so that engineering can be executed in a manner that is adapted to Kvaerner's build sequence. Because the bottom line is the main driver, the project team do not need any additional drivers. As long as Kvaerner manage to explain what the requirements are and why the requirements are the way they are, the engineering subcontractor get insight in what is needed to be able to increase the bottom line. To support this, they carry out what they call inductions, which is an introductory package for the engineers as they come aboard the project.

For Kvaerner, success is also related to the competence and experience of the project team. Most project participants bring along experience from the last project – in terms of both methodology, requirements and deliverables. It will always be a challenge to include those who were part of the project last time when an engineering subcontractor mobilizes for a new project together with

Kvaerner. If they repeatedly get more common projects ahead, they can adapt to each other better. Kvaerner has experienced that if they have 70% engineers who have been part of a project team that worked according to the requirements in Kvaerner's PEM, there is a great chance that it goes better in the new project than the last time. If they have 30% engineers who have worked according to the requirements in Kvaerner's PEM and 70% beginners, there is a great chance that the new project will not turn out well. To succeed in future EPC projects, it is important to seek a form of strategic alliance with the preferred engineering subcontractor, and use the same from project to project. Experiences from strategic alliances that Kvaerner has today with engineering subcontractors, indicate that there are virtually no conflicts.

# 5. Technology

When the engineering subcontractor works in the BIM without the contractor having set the boundaries for the different sections, they work relatively unhindered. Disciplines work with the entire platform, because many of the objects modelled go through several sections. Kvaerner has experienced that to get a discipline to split the model in objects that are going onto to the different sections, when the boundaries are set, is a challenge to accomplish, and increases the complexity, with many interfaces. It is an added cost, and more time consuming, because the discipline must spend time to go in and out of the sections. There is a maximum limit to how much parallelism one can manage in that context. The splitting of the BIM towards fabrication and construction are based on the main areas as defined by the contract. The sub areas, called fabrication assemblies, are defined by Kvaerner to control the parts that are sent out for fabrication. All necessary documentation, including drawings, are related to each fabrication assembly. FAS (fabrication assembly section) express the horizontal area, and FAV (fabrication assembly volume) the volume above. FAS is the first that comes into production. FAV is established when they have added several sections that are finished. Some of the planned activities go towards the area, while some of the activities goes towards the volume. There are certain activities that requires several volumes composed simultaneously. For instance, a cable can not be cut from volume to volume, and must be drawn as one cable. Cable activities are planned against all volumes it goes through A pipe can be split, because it must be welded together.. Piping activities may be connected against each FAV, because they can draw out the pipes and welds between them. Fabrication assemblies are similar to what Jaafari (1997) define as clusters, referring to particular parts of the project. Clusters can include relevant front-end activities, procurement and construction activities. Each cluster can be assigned to a team and executed as an integrated part. Similarly, Luth et al. (2013) states that sequencing knowledge and methods, in addition to construction means, can be incorporated in the BIM, in order to reach a sufficient quality level to produce drawings for construction.

Anumba and Evbuomwan (1997) define the aim of concurrent engineering (CE) to reduce lead times and improve quality and cost by integrating fabrication in design, and maximizing parallelism. When engineering starts it is required that all large and heavy equipment are identified. According to Kvaerner, the disciplines need all design parameters of what they call critical packages (weight, where bolt holes are, where pipes are to be connected, how cables should be plugged in etc.). That is governing because the disciplines need to get this to fit together

(the floor needs to support the weight, any rotating equipment must withstand the rotational forces etc.). The bigger and more expensive equipment, the longer time it takes to fabricate. It is therefore important to get this equipment ordered as early as possible, to get the vendor drawings and to get it delivered on time. The sequence of purchase orders is made based on criticality. Kvaerner define criticality in terms of how much equipment (i.e. the information on the equipment) are of importance for the design development, and is categorized from 1 to 3, where 1 is the most demanding equipment ("long lead items") and 3 is the least demanding. Preliminary information of equipment is based on the initial purchase orders and used as important input to the fabrication assemblies. The information is updated when the orders are finalized.

# 6. Discussion

Are the findings on process, people and technology in this paper relevant towards the construction industry? The IDDS approach, which aims to utilize BIM and make sure that improvements in construction projects are based on a combination of process, people and technology, is used to assess this. IDDS consist of four main elements; collaborative processes, knowledge management, enhanced skills and integrated information and automation systems (Owen et al., 2009). Process, people and technology are closely related and mutually dependent. Findings on process can be related to collaborative processes and knowledge management, where the latter also have a close interface towards people and technology. Findings on people can be related to enhanced skills, while findings on technology can be related to integrated information and automation systems (see illustration in Figure 2). The conditions and main challenges each of these elements address, have been briefly identified, followed by how key findings on process, people and technology can address these.
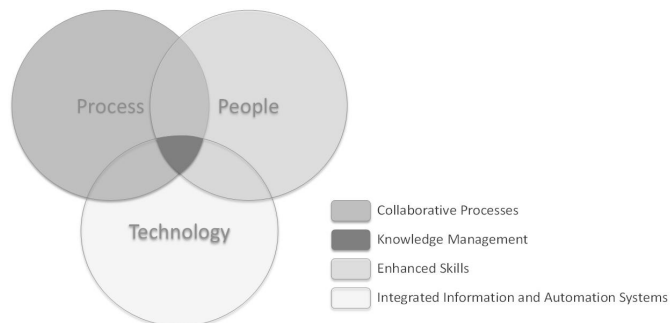


*Figure 2 Relation between process, people and technology and the four elements of IDDS*

Collaborative Processes: Improved design and delivery through better coordination and integration is essential. To support this, information technology tools will need to provide increased capability for knowledge sharing and development, rather than for just information exchange, aggregation and storage. Collaborative approaches, linked with an effective knowledge management system, would facilitate this. Further benefits may result from adoption of new approaches to work processes being developed in other sectors (Owen et al., 2010). Kvaerner's ambition is always to build in as short time as possible and have as high parallelism as possible

and as few working hours as possible, but at the same time meeting the quality requirements. To be able to work integrated, the EPC contractor must describe the build sequence for the engineering subcontractor, so that they manage to deliver their drawings and materials into that specific sequence. PEM shall ensure that the status on the engineering deliveries at the last milestone in the design phase satisfies Kvaerner's build sequence.

Knowledge Management: Codified knowledge in companies typically exists within individual groups (discipline, trade, function) and is seldom shared with others. Applying knowledge management, which includes codifying, using and constantly updating critical knowledge and business processes, is only done in a few leading companies (Owen et al., 2010). PEM supports "right the first time" through milestone requirements, to make sure engineering has come as far as required to start construction. Kvaerner's milestone requirements in the design phase are compared to the engineering subcontractor's corresponding milestones. The gaps are identified, and additional requirements are added to their milestones. In that way the engineering subcontractor can keep their own milestones but with certain additions (or deductions) to support Kvaerner's build sequence. The core to success is that Kvaerner is able to get the message out to the disciplines. Kvaerner's PEM, which is knowledge management in practice, has two functions in respect to that; tell the disciplines what they should have done at a given milestone and to check whether it is achieved.

Enhanced Skills: Increased performance requirements and complexity in construction increase the need for integration skills. Furthermore, project management in integrated projects need to focus on personnel with shared technical knowledge and integration experience as key selection criteria. Knowledge of prior projects and current requirements, will foster integrated work processes both between and within specific project phases and major activities (Owen et al., 2010). A joint venture with a common bottom line, that Kvaerner and the engineering subcontractor has established, with clearly defined project goals, which the parties have to align to, will increase the motivation to integrate for both contracting parties. The main advantage of an incentive-based contract, such as joint venture, is its potential to unite the objectives of the project team with project objectives. Kvaerner must get the engineering subcontractor to adapt to their build sequence and not what they have done towards other EPC contractors. That is what Kvaerner and the engineering subcontractor have spent time on in the relevant case project. If Kvaerner manage to get a new project with a majority of the same personnel, it would further improve integration.

Integrated Information and Automation Systems: Moving towards partial integration and automation of engineering, procurement and construction, will increase the overall performance of a project. This includes extracting information for fabrication from the design model. Further progress will require providing more complete design information models for use in in construction (Owen et al., 2010). This is what Kvaerner has moved towards, when they split the BIM in sub areas, called fabrication assemblies. These are developed to be able to define and control what is sent out for fabrication. Drawings and all other relevant information is related to each fabrication assembly. Kvaerner has three categories of criticality, which is related to design and delivery time on equipment. Information on equipment is based on the purchase orders, and

will be updated as the orders are finalized. This is used as important input to the fabrication assemblies.

# 7. Conclusions

This paper has identified how transition from engineering to construction can be improved, based on experiences from offshore projects in the oil and gas industry through Kvaerner, executed as EPC contracts (design-build), with engineering and procurement on a subcontract. The results are structured according to three interrelated dimensions; process, people and technology. The first dimension, process, is related to parallelism and build sequence. Construction is pushed in parallel with engineering, because of the short time frame from contract is signed to delivery date. To get deliveries at the right time, Kvaerner has made a build sequence, according to their project execution model (PEM), that engineering and procurement must know and deliver according to. At the last milestone in the design phase, M2C, the design should be at a quality level that is required to start construction. PEM supports "right the first time" by defining requirements on the milestones in the design phase. The M2C milestone is checked against the corresponding milestone to the engineering subcontractor. The gap is identified and any additional requirements are added to the milestone to the engineering subcontractor, so that they can satisfy Kvaerner's build sequence and deliver "right the first time". The focus for the next dimension, people, is related to common incentives and drivers, and how Kvaerner can make sure that the engineering subcontractor adapt to the build sequence and align their milestones. Through a joint venture, where they share profits on the bottom line in a percentage distribution, the incentives are higher for both parties to satisfy, compared to a standard subcontract, because they are mutually dependent on each other. It is crucial that Kvaerner can influence the disciplines to adapt the design and deliveries to Kvaerner's build sequence. Success is related to the use of experienced and competent personnel on both sides in the project team that are commercially conscious to what mechanisms apply in the contract, and act according to that. The last dimension, technology, is related to the use of BIM and how it must be split into sub-areas, fabrication assemblies that contain all relevant information and is optimized for Kvaerner's build sequence. Criticality related to lead-time on equipment and availability of correct vendor information at the right time will be important input to fabrication assemblies. The IDDS approach (Owen et al., 2010) is applied to increase the relevance of the findings towards the construction industry. It consists of four main elements and identify challenges in the industry on BIM and process, people and technology. Several of these challenges have been addressed with the findings in this paper, which increases the relevance towards the construction industry. Future research will focus on gathering additional data related to process, people and technology and analyze that to further develop concepts, for adaption towards the construction industry.

# Acknowledgements

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Paper 8

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# COLLABORATION AND BIM SUPPORTIVE PROJECT EXECUTION MODEL FOR THE CONSTRUCTION INDUSTRY

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**Abstract:** *Currently, the construction industry is characterized by a situation where each actor utilizes their own project execution model, documenting an ideal internal workflow for project execution. These models usually ensure the needs of each individual actor in a construction project. Building Information Modelling (BIM) supportive aspects and collaboration related aspects are however often insufficiently covered. A common project execution model attending to both the principal needs of each individual actor and collaboration between actors, would be a major driving force for a more efficient project execution. In addition, incorporation of cross-level/-actor BIM aspects would most likely cover the shortcomings of present project execution models. Few research results are pointing to the specific challenges of the actors when collaborating in BIM projects, and of their use of individual project execution models. How could a mutual and agreed project execution model, supporting present standards, increasing complexity, demands for collaboration, and the use of BIM, meet present and future needs?*

*We have employed a differentiated methodology, with a workshop development approach and a key personnel verification approach to develop an agreed, common project execution model for implementation and testing through a qualitative case study in the Norwegian research project "Collaboration in the building process - with BIM as a catalyst" (SamBIM), funded by the Research Council of Norway. The project partners are four industry-leading construction companies, and three major research institutions. The execution model is contractually independent, at a strategic and tactical building process level, from concept to operation. Potential benefits of BIM are visualized. Our qualitative case study findings support initial project hypotheses, and provide a good basis for improvement of current project execution models towards improved BIM based collaboration with a common project execution model.*

## 1. INTRODUCTION

The construction industry has seen an increase in larger and more complex projects. Increased complexity means increased quantity and interdependence of design components in projects. [1] This imply an increased focus on management of projects, increased interaction and collaboration between actors and increased utilization of BIM. Without a common frame of reference, it is natural with many misconceptions and difficult discussions in projects. A way to solve this is by introducing project execution models (hereafter called execution models), documenting an ideal internal workflow for management and execution of construction projects. The challenge is that these execution models usually are arranged to ensure the specific needs of each individual actor in a construction project. They do not usually support comprehensive collaboration or a common goal between the actors, which is necessary to meet consecutive changes in framework conditions and increasing project complexity in the construction industry.

Presently, new initiatives of execution models are rapidly being developed by actors in the construction industry. This results in a complex and confusing situation for collaboration within construction projects and for decision makers. There is not one main, leading initiative. An ideal approach would be to lift, improve, and further develop existing initiatives and/or to incorporate the most promising aspects from several initiatives into one common initiative. Instead, new confusing varieties are emerging that in practice are aggravating the situation and making it even more complex.

A common execution model in which both the principal needs of each individual actor are met, and collaboration between actors are attended to, would be a major step forwards towards a more efficient project execution. One of the strongest arguments for utilizing BIM in the construction industry is that it will lead to improved collaboration among the actors. If cross-level and cross-actor BIM aspects were incorporated, it would most likely cover the shortcomings of present execution models. The result would be that all actors would have a common understanding and work towards common goals.

There are industry initiatives and research [2] describing execution models, both at national and international levels. Few initiatives and research results are however pointing to the specific challenges of the actors when collaborating in BIM projects, and of their approaches towards the use of execution models. This is part of the background for developing a common execution model. The arguments are to introduce common terminology, increase knowledge and awareness among project participants in how construction projects are to be executed, ensure that necessary decisions are taken at the right time, and ensure good project management and coordination of project participants. A common execution model, that supports the use of BIM, could meet the needs evolving from increased project complexity and demands for collaboration.

Findings are based on the Norwegian research project "Collaboration in the building process - with BIM as a catalyst" (SamBIM), funded by the Research Council of Norway. The project partners are leading and R&D active companies in the Norwegian construction industry: Statsbygg (building owner), Skanska (contractor), Multiconsult

(engineering consultant) and LINK (architect). These companies represent important parts of the building process value chain. The interdisciplinary research group consists of SINTEF Building and Infrastructure (largest independent research organization in Scandinavia), FAFO (one of Norway's largest institutes on social science research) and NTNU (Norwegian University of Science and Technology). The main goal of SamBIM is to develop BIM-driven processes and collaborative models that increase value creation in construction projects for the construction industry and in the SamBIM partner companies (project partners).

SamBIM has developed a contractually independent execution model at a strategic and tactical level, with a description of phases, stages and milestones. The scope covers the building process from concept to operation. Based on a stage-gate principle, a logic with input and output of stages, and main activities with dominant and supportive actors, has been established. Potential benefits of BIM have been described and visualized for each actor within each stage. The structure has been defined at levels that are common to the industry. Further specifications on an operational level will be unique to each project partner, and are not performed as part of SamBIM.

## 2. RESEARCH METHOD

Through an action research-based case study, researchers and project actors have interacted case projects in the construction industry. When developing a common execution model, as part of the study, SamBIM have employed a differentiated methodological approach, with two main directions: a workshop development approach and a key personnel verification approach. Several initial workshops founded the documentation of the different partners' current execution models, and established propositions to improve and harmonize these. A task group conducted an in-debt study, and further processing resulted in a common execution model. Finally, a verification was performed, through interviews and discussions with key partner personnel and discussions in the main project work group. The output was an agreed, common execution model for implementation and testing through the qualitative case studies in SamBIM.

A main principle in the course of development was a desire to develop one common, unified and interdisciplinary execution model, to display an ideal, BIM-supported process. The SamBIM project partners have, despite an industry dominated by competitiveness, contributed with their unique knowledge and opinions of how and what the ideal process could possibly be like. With leading roles in the industry, they have mutually shared experiences of their organization's internally developed execution models and practice from several Norwegian construction projects. Correspondingly, the research partners have provided valuable experiences and results from other research and international benchmarking.

Initially several workshops were carried out in the SamBIM project, aiming at documenting present project execution practices, inducing necessary improvements, and arrive at an optimized process to be implemented in the ongoing case studies of the SamBIM project. In the strategic approach in developing the execution model, the main

roles/areas of responsibility were defined, the process was broken down into stages, with appurtenant ownerships defined, and stage gates were defined and described in the execution model. To what extent BIM was implemented, was documented on the basis of the current situation to each industry partner. The results were documented in a graphical presentation appearing as a process chart with extended information. In order to obtain a quality assurance of the results, interviews of key personnel from all the participating partners in the SamBIM projects were planned and executed, focusing on the stages were each partner were dominant in terms of roles and responsibility areas.

## 3. SAMBIM PROJECT EXECUTION MODEL

### 3.1. Principles and structure - SamBIM project execution model

The SamBIM execution model describes a workflow from the initiation to disposal of a construction project. The execution model is structured through levels that are common to the industry. The result is a hierarchical and contractually independent execution model at a strategic and tactical building process level. The strategic level describes the phases, stages and milestones. The top level defines phases, decision gates and stages with corresponding milestones (see Figure 1). The transitions between the phases are controlled by decision gates, displayed at the strategic level of the model, involving both an evaluation of activities and results of the preceding phase, and planning of the next, as a two-part control.
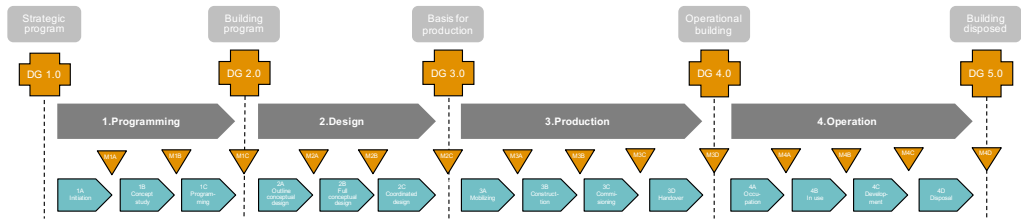


Figure 1: Strategic level of SamBIM execution model, with decision gates, phases, milestones and stages

The structure of the execution model is based on phases at a strategic level and are common to all actors. These phases describe the process at a principal level and consists of stages. Based on a stage-gate principle, a logic with input and output of stages and main activities is established (see Figure 2). Milestones, as control points between the stages, distinguish the different stages. The control is performed in two directions; backwards evaluation and forwards planning. For the stages in each phase, the dominance of the actors is pin-pointed, according to a color-coded model. The color codes are red (dominant actor), green (active actor) and blue (passive actor). The key actors are building owner (O), architect (A), engineering consultant (E), contractor (C) and user (U).

The transitions between the phases in SamBIM are distinguished by an exchange of roles, and is often referred to as a "handover of a relay baton". The roles may change between actors, but the role of one actor may also change.
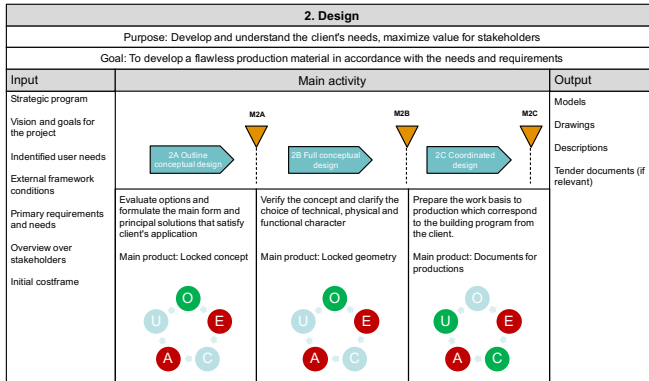
Figure 2: Strategic level of SamBIM execution model with logic and structure of stages

An example is the transition between the *Programming* and *Design* phases. The owner's role is changing from being a leading phase owner and responsible of brief in *Programming*, to becoming a decision maker in the *Design* phase, without any leading role beyond merely being present for decision making purposes in the rest of the building process. At the point of acquisition, the owner repossesses the dominant role. In all phases, there are different dominant roles. In the *Programming* phase,it is the owner who possess the dominant role, as in the example. In the *Design* phase, the designers are dominant (most often represented by the architect or engineering manager). In the *Production* phase, the contractor is the dominant actor, and in the *Operation* phase the user is the dominant actor. This set-up of actors will change for each stage within each phase, according to contract practice. The SamBIM execution model offers a basic picture of the most common set-up of actors, thus the model is contractually independent. It is however flexible, and may be accustomed to a set-up by choice.
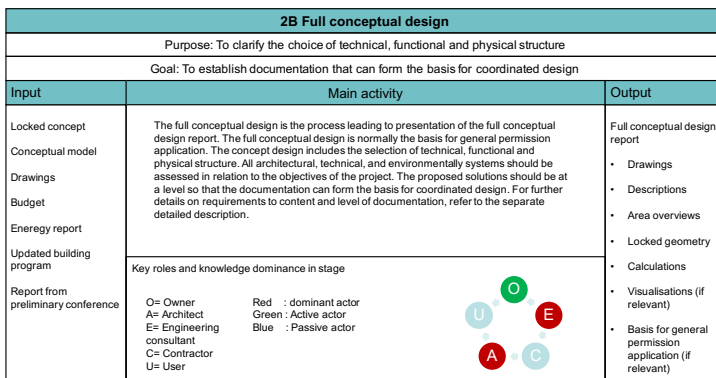


Figure 3: Tactical level of SamBIM execution model with logic and structure of stages

The stages within each phase describe the level of which the actors work. Each stage

consists of multiple quality levels, describing the degree of completion. Each quality level consists of activities performed by one or more actors. As with phases, each stage is based on a stage-gate principle, a logic with input and output of stages and main activities. The dominant, active and supportive actors are pin-pointed, according to a color-coded model (see Figure 3). Potential benefits of BIM are visualized at the level of activity within each stage, through a flowchart (see Figure 4). The flowchart is based on the stage-gate principle, and consists of input and output deliveries, and key activities. All disciplines are differentiated with symbols. Color codes represent the degree of BIM use for an activity/delivery. Further specifications will be unique to each project partner, and are thus not performed in this project.
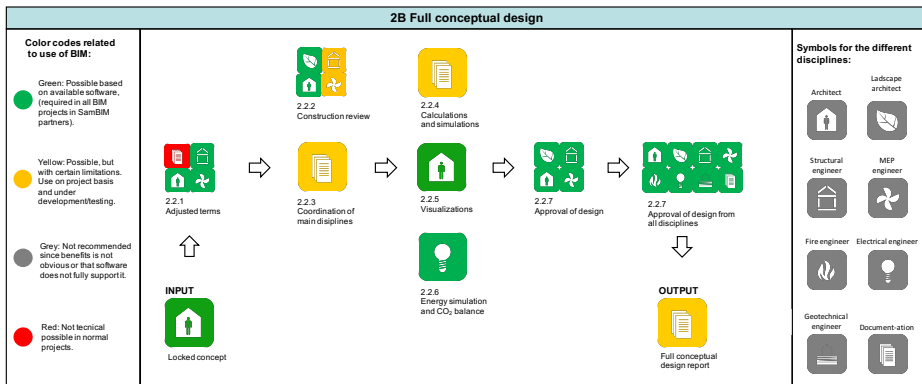


Figure 4: Tactical level of SamBIM execution model with flowchart of actors, activities and BIM use

### 3.2. Experiences from the case projects in SamBIM

The experiences learned across the five SamBIM cases have been highly valuable in many respects. The cross-case analysis has helped understanding how things may differ between projects, contracting models and -practices, strengthening the value of findings when reappearing in more or all cases, and seeing the development step-by-step between the cases in the course of the project. These three strengths lie within the choice of method; the cases are not sharing all partners, they are not parallel, nor consecutive, but are incorporated in the SamBIM project on a need-a-case basis. The analysis indicates that:

- The anchoring of a project in the organizational management, and correspondingly, the rooting of the project at the bottom line of an organization, affects the results of the project, and how successful it is comprehended by the involved parties.
- The earlier the involvement of all actors in the building process, the more successful is both the collaboration and the result of the process.
- Different partners have different goals, or varying aims of the process
- A collaboration strategy encompassed in a common execution model will provide a psychological ownership of the project for all involved parties.
- Common project group goals in terms of a strategy that provides a collaboration

method makes the group move in the same direction, and is positive for the general outcome of the project.

## 4. COMPARISON TO OTHER INDUSTRY INITIATIVES

The SamBIM execution model (hereafter called SamBIM) is divided in four main phases and 14 stages, and is used as a benchmark when compared to other similar industry initiatives (see Figure 5). Light grey, grey and dark grey, respectively, indicates high, medium and low degree of similarity compared to the stages in SamBIM.

| Initiative | Row | 1A | 1B | 1C | | 2A | 2B | 2C | | 3A | 3B | | 3C | 3D | 4A | 4B | 4C | 4D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SamBIM | Phases | 1 – Programming | | | | 2 – Design | | | | 3 – Production | | | | | 4 – Operation | | | |
| | Stages | 1A | 1B | 1C | | 2A | 2B | 2C | | 3A | 3B | | 3C | 3D | 4A | 4B | 4C | 4D |
| | | Initiation | Concept study | Programming | | Outline conceptual design | Full conceptual design | Coordinated design | | Mobilizing | Construction | | Commissioning | Handover | Occupation | In use | Development | Disposal |
| "Neste steg" | Phases/Stages | 1 | 2 | | | | 3 | 4 | | 5 | | | | 6 | 7 | | | 8 |
| | | Strategic definition | Brief development | | | | Concept development | Detailed designing | | Production | | | | Handover | In use | | | Termination |
| RIBA PoW | Stages | 0 | 1 | | | | 2 | 3 | | 4 | 5 | | | 6 | 7 | | | |
| | | Strategic definition | Preparation and brief | | | | Concept design | Developed design | | Technical design | Construction | | | Handover and close out | In use | | | |
| ISO 22263 | Phases | Inception | Brief | | | | Design | | | Production | | | | | Maintenance | | | Demolition |
| ISO 29481-1 | Phases | Pre-life-cycle phase | | | | Pre-construction phase | | | | Construction phase | | | | | Post-construction phase | | | |
| | Stages | 0 | 1 | 2 | 3 | 4 | 5 | 6 | | 7 | 8 | | | | 9 | | | 10 |
| | | Portfolio requirements | Conception of need | Outline feasibility | Substantive feasibility | Outline conceptual design | Full conceptual design | Coordinated design (and procurement) | | Production information | Construction | | | | Operation and maintenance | | | Disposal |
| bSN Guide | Phases | S00 | S01 | S02 | S03 | S04 | S05 | S06.1 | S06.2 | S07 | S08.1 | S08.2 | S08.3 | S08.4 | S09 | | | S10 |
| | | Portfolio requirements | Conception of need | Outline fisibility | Substantive feasibility | Outline conceptual design | Full conceptual design | Coordinated design | Procurement | Production information | Construction | Off-site construction | FM/Operation documentation | Commissioning | Operation and maintenance | | | Disposal |

Figure 5: Comparison matrix of industry norm initiatives and standards, with SamBIM as benchmark

The most relevant initiative for an industry norm to compare the SamBIM execution model with, is "Neste steg" [3] ("Next stage"), because both are originating from Norwegian actors and focusing on the Norwegian construction industry. "Neste steg" is a proposed new norm for a phased division of the construction process. It was launched by the governmental initiative Bygg21, in November 2015. The eight stages in "Neste steg" is at a detail level between the phases and stages in SamBIM. The main difference is that the term *Outline conceptual design* is not used, and is instead included in the second stage in "Neste steg", *Brief development*. It is argued that *Brief development* includes *Outline conceptual design* because several concepts are still being developed. The consequence is that *Brief development* is both part of the phase *Programming* and *Design* in SamBIM. According to SamBIM, each phase has a different dominant actor. *Programming* has the building owner as a dominant actor. *Design,* where *Outline conceptual design* is the first stage, has the architect and engineering consultant as dominant actors. Another difference is that the term *Full conceptual design*, which in SamBIM is the second stage in *Design*, has been changed to the term *Concept development* in "Neste steg". The first three stages in the *Production* phase in SamBIM have been merged to one stage, *Production*, in "Neste steg". Similarly, the first three stages in the *Operation* phase in SamBIM have been merged to one stage, *In use*, in "Neste steg". The stages in "Neste steg" is based on RIBA Plan of Work [4], with three main differences. The first is that the second stage in "Neste "Neste steg", *Brief development,* is divided in two stages in RIBA PoW, *Preparation and brief* and *Concept design*. The second is that the fourth stage in "Neste steg", *Detailed engineering* is divided in two stages in RIBA PoW, *Developed design* and *Technical design*. The third is that "Neste steg" has added an additional stage, *Termination*, which

do not have a corresponding stage in RIBA PoW.

ISO 29481-1 [5] describes the processes undertaken in the construction process. The scope (and extent) of the four main phases in SamBIM corresponds with the four main phases in ISO 29481-1. It also corresponds to the main phases in ISO 22263 [6], except the first and last phase, which in ISO 22263 both are divided in two. The stages in SamBIM also corresponds with the stages in ISO 29481-1, with two main exceptions. Stage 1C *Programming* is divided in two stages in ISO 29481-1; stage 2 *Outline feasibility*, where the feasibility of options is presented, and stage 3 *Substantive feasibility*, where financial approval of chosen options is gained. Stage 3B *Construction*, 3C *Testing* and 3D *Handover* is converged into stage 8 *Construction*, where the product is produced according to client requirements with a handover as planned.

buildingSMART Norway has created a guide (bSN Guide) [7] for requirement specifications on the use of open BIM in construction projects in Norway. The phases in bSN Guide is based on the stages in ISO 29481-1, with two deviations. The first is stage 6 *Coordinated design (and procurement)* in ISO 29481-1, which has been divided in two phases; S06.1 *Coordinated design* and S06.2 *Procurement* in bSN Guide. The second is stage 8 *Construction* in ISO 29481-1, which has been divided in three phases; phase S08.1 *Construction*, S08.2 *Off-site construction* and S08.3 *FM/Operation documentation* in bSN Guide.

To summarize, the sources used in the comparison have different degree of similarity with SamBIM. If we compare the phases, ISO 29481-1 have the highest degree of similarity, followed by ISO 22263. If we compare the stages, ISO 29481-1 have the highest degree of similarity, followed by bsN Guide, RIBA PoW and "Neste steg".

## 5. DISCUSSION

The SamBIM execution model was shaped primarily as a result of the SamBIM partners' existing execution models and comprehension of building process phases. In practice, it turned out difficult to get definite feedback on the documentation in the execution model draft, especially at stage-level and lower. It was surprisingly hard to induct other parties into the logic of the execution model. We got no tangible suggestions for improvements. In retrospect, this difficulty was not initially foreseen. A probable reason might be that the project partners' operate at very different levels in the hierarchy of the execution model, making it difficult to see others' challenges further down in the execution model (at stage level). As an example, the owner is situated higher up in the hierarchy than e.g. the contractor. This indicates the existence of a limited understanding of each other's levels and general operations or activities, and is thus a barrier for ideal interaction. When comparing with other execution models, the SamBIM execution model seems indeed more complex, however not too complex to grasp for professionals, trained in reading process charts, and experienced in using project execution models.

Presently, it is often assumed that all parties have the same objectives in a building process. If so, it would be easy to achieve and maintain an ideal collaboration throughout any construction project. Findings in SamBIM demonstrate that this is often not the case.

Divergent goals are often under-communicated when discussing how to improve the interaction, but if taken into account, it may contribute to achieving a more complete understanding of the different roles, by incorporating different sub-goals into one execution model. Collated with contracting practices (who is whose client), and contractor models, there is a huge potential of optimization within of the completion of a construction project. One way to overcome the challenge of individual actor goals is to envision each phase as "owned" by an actor, that his operator is dominant in the current phase and thus has the greatest power (situational). While it is important to safeguard clear transitions in the interfaces between actors in adjacent phases, such awareness will help to create a more thorough understanding of different roles and each other's goals. A common execution model that provides a mutual strategy for collaboration will also contribute to creating ownership of the project for all parties involved. Thus, the need for anchoring a project both at management level and at "the bottom line" are met when employing such an execution model.

When it comes to differences with other industry initiatives, it is a challenge that the SamBIM execution model is diverging from "Neste steg" in several ways. Even if it is more natural to compare the SamBIM execution model with "Neste steg", SamBIM execution model is more in line with the ISO standards and bSN Guide, and even RIBA PoW. "Neste steg" is much closer to the international (UK) RIBA PoW, and is thus less synchronized with the rest of the Norwegian construction industry. New ideas introduced by the "Neste steg" for the industry is very positive. Still, it is important to remember that i.e. contracting and contract practices are not similar in Norway and in the UK.

## 6. CONCLUSIONS

The paper presents a mutually agreed, common project execution model ready for testing and implementation. Founded on a qualitative case study to establish the current requirements to such a model, the model development method is differentiated. We have employed a workshop development approach and a key personnel verification approach in shaping the model.

The SamBIM project execution model is based on a stage-gate principle, with the use of input, main activities and output. This forms the basis for the description of all phases, stages and corresponding flowcharts within each stage. Input defines the start product that must be in place in order to initiate the main activities. Similarly, output defines the end product that must be in place in order to complete the main activities. Milestones are defined at the end of each stage and describe a desired state that must be fulfilled. Use of BIM is essential to get a good information flow in practice, and is reflected in the flowchart that is developed for each stage. The SamBIM project execution model is not tested and fully implemented in construction projects. However, it has been presented in different forums, and has been introduced to a selection of academics within the area of expertise in Norway, with positive feedback and interest. The research and innovation project, SamBIM, which the development of the project execution model is a part of, is coming to an end in the second half of 2016. Being based on several individual industry partners' execution models, it does however provide a good basis for an improvement of

current execution models towards a more mutual and agreed consensus execution model. The case study findings in the SamBIM project are about to be summarized, and should thus support the final development and completion of the SamBIM project execution model. Based on the comparison with other industry initiatives presented in this paper, an alignment with ongoing and present initiatives should also be performed, prior to a final testing by the SamBIM partners and presentation to the construction industry.

Seeing that there is much common ground between the various execution models in the industry today, it should be possible to agree on a common industry norm for project execution, on a principal level. Because there is a difference between projects and between project partners, there will be need for adaptations. Having a common industry norm provides obvious advantages in collaboration and project execution. If all the actors involved in a construction project relate to the same phases and stages, it can reduce waiting, error correction, waste and misunderstandings. It can increase productivity, ensure that deliveries arrive on time, and contribute to more effective communication between all actors.

The SamBIM model, supported by the use of BIM, is based on and takes hold in a number of significant principles that it will be important to pursue. Further, the development of the SamBIM model as a collaboration between the professional actors and the researchers has been inspiring and fruitful, and has contributed to increase the robustness of the execution model. The cooperation demonstrate that it is indeed possible to obtain a common execution model covering different organizations in the building process. If the SamBIM project execution model can be aligned with the other initiatives in the construction industry, and thus contribute to the development of a common industry norm for project execution, the main goals for the SamBIM project will be fulfilled.

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