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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*

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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.

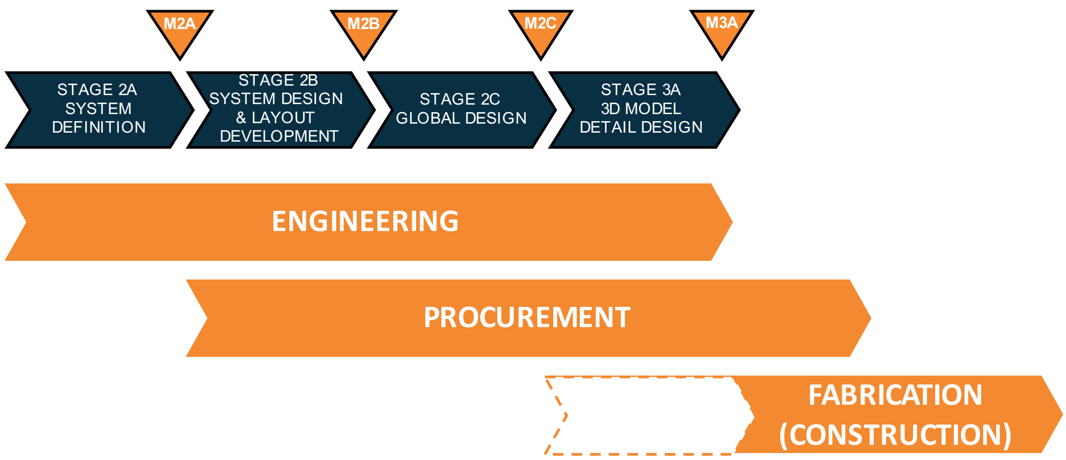

FIG. 1: Stages and milestones in the PEM in detail engineering compared to project steps (AkerSolutions, 2014a, AkerSolutions, 2011)

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).

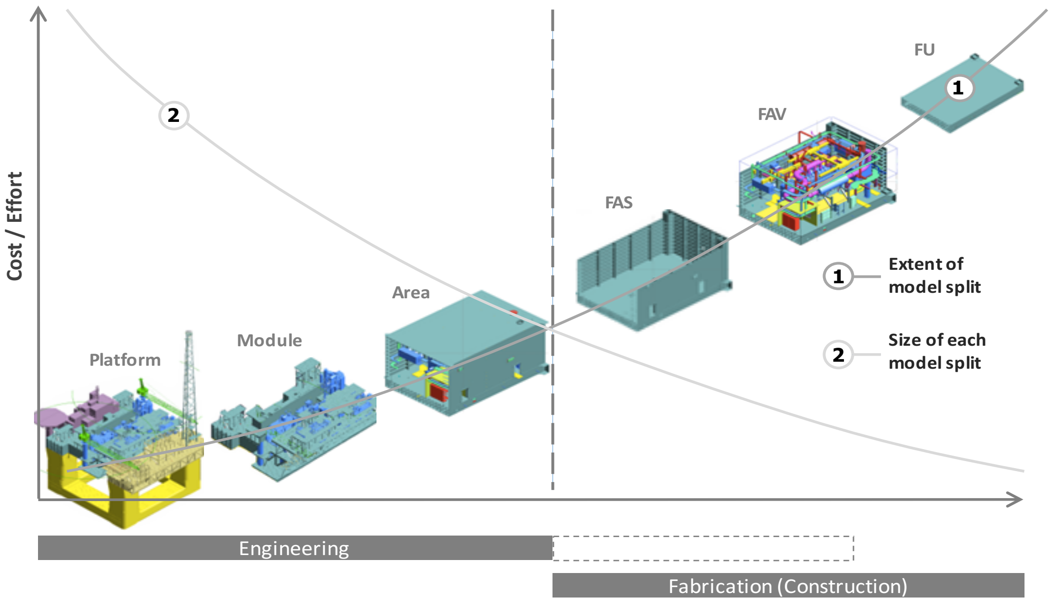

FIG. 3: Model split in engineering and fabrication in EPC projects. Adapted from Kvaerner (2016)

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).

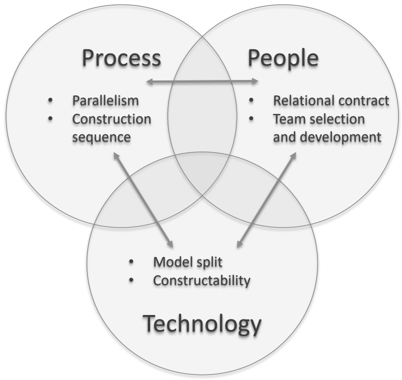

FIG. 4: Findings related to process, people and technology

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.

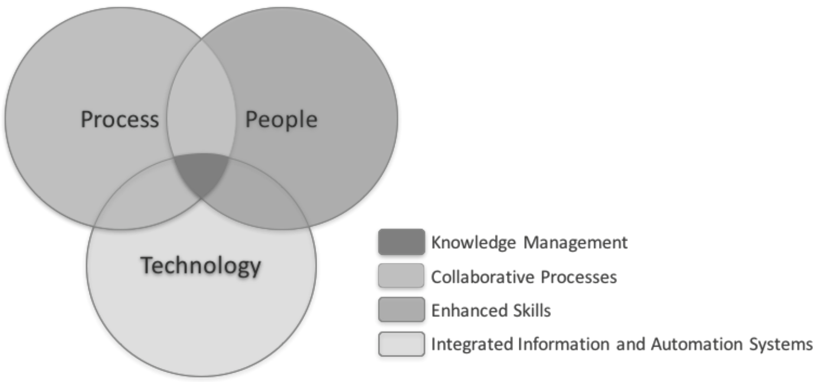

FIG. 5: Relation between process, people and technology and the four elements of IDDS. Adapted from Owen et al (2010)

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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