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Using a change control system and building information modelling to manage change in design

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ABSTRACT

Today, there are few satisfying change management systems to handle changes in design, both internal changes initiated by the engineering team and external changes initiated by the client. How can changes in design be managed using a change control system (CCS), and how can building information modelling (BIM) be utilized to optimize evaluation of changes? This paper introduces a change management process and a corresponding CCS for managing changes in detailed design, and assesses how BIM can be used to identify consequences of changes. Findings are based on experiences from execution of major oil and gas projects. Data are gathered from projects, primarily through a Norwegian engineering, procurement and construction (EPC) contractor, using case study research. The research portrays how changes can be handled using the CCS. When a design change request is created, it is presented to a Change Board, where it is processed, categorized, evaluated and either approved or rejected. BIM is used to consider impact and consequences for affected disciplines. The client will be added in the decision process and presented for cost and schedule impact. Results indicate that the dynamics of the CCS combined with the utilization of BIM can keep control of changes in detailed design and reduce overall impacts of changes.

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Building information modelling; change control system; change management process; design change; project execution model

Introduction

In the construction industry, project changes occur at all stages of design and construction, with decisions that often have to be made based on incomplete information, assumptions and experiences from professionals (Shen et al., 2010). In the beginning of detailed design, everything changes because there is a design development that by nature is a period where various concepts and alternative solutions are developed and evaluated. When going into detailed design, the conceptual development should be concluded and design gradually frozen. When the design is frozen, it should by definition not be changed. According to Jarratt, Eckert, Caldwell, and Clarkson (2011), objects that are frozen can only be changed at great cost. Engineering teams may implement changes in design without fully understanding the potential impact on the cost and schedule (adjusted milestones and/or end date) of the project, or the effect on contractual requirements, as specified by the client. According to Isaac and Navon (2009), this is because the tools currently used for project planning and design in construction are not able to evaluate the consequences of a specific change, before the plan and design are fully updated. As a result, deviations from client

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objectives, caused by changes in the project, are often revealed late in the project or after its completion.

This paper introduces a change management process and a corresponding change control system (CCS) initially developed by a Norwegian engineering, procurement and construction (EPC) contractor, for use in major offshore and onshore projects in the oil and gas industry. The hypothesis is that the CCS can be adapted to the construction industry and be used for managing changes in larger multidisciplinary projects. The foundation for this is supported by the research question: How can changes in design be managed using a CCS, and how can building information modelling[1] (BIM) be utilized to optimize evaluation of changes? The goal has been to develop a flowchart that define the principles of the CCS, as used by the EPC contractor in detailed design, and how the use of a 3D design environment,[2] or BIM as the corresponding term in the construction industry, can identify impact and consequences of changes in detailed design. Jarratt et al. (2011) have presented various tools to support workflow and decision-making in engineering change management, but none that combined and explicitly addressed these aspects to support their engineering change process. Using the CCS, engineering teams are able to evaluate implications of changes in detailed design, both internal changes initiated by the engineering team and external 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 change could cause the project to deviate from its original goals, or if special measures have to be considered, before it is implemented. The EPC contractor has developed a project execution model[3] (PEM), which defines requirements that must be achieved to reach the quality level at each milestone to each stage in detailed design. The maturity of the design differs within and between disciplines at each quality level. When the design has reached a certain quality level where the majority of the objects are frozen, drawings for construction can be issued. This paper focuses on two aspects related to a 3D design environment (hereafter called BIM) and changes in detailed design. The first is to use BIM as part of evaluating change requests in the CCS. The second is the use of BIM towards frozen design, related to milestone requirements through quality levels, as defined in the PEM.

As a background, this paper investigates what constitutes a change and identifies the main types of changes, as defined by the EPC contractor. The findings are divided in three parts. The first part defines the change management process at the EPC contractor, and compares it to research on corresponding processes towards the construction industry. The second part describes the principles of the CCS based on how it is applied in detailed design at the EPC contractor, from a change is identified to the change is implemented. A flowchart has been developed by the author to illustrate this. Research on similar change management systems in the construction industry is identified. The third part describes how BIM is utilized as an integrated part of the CCS and how it relates to frozen design. In the discussion, benefits and further development of the change management process and the use of the CCS, in relation to those identified in the construction industry, are identified. The use of BIM and coherence between cost and ability to impact changes in design is discussed. The relevance and applicability towards the construction industry is pinpointed. The conclusion summarizes the key findings and suggests future research.

Research method

The research is qualitative, and conducted as case study research. Data are gathered from three case projects in the oil and gas industry, primarily through a Norwegian EPC contractor. The case projects are delivery of topsides of production platforms on the Norwegian continental shelf, executed as EPC contracts, which corresponds to design-build contracts in the construction industry. The first two have been the topsides for the Edvard Grieg and Eldfisk platforms, both delivered in 2014, executed with engineering and procurement on subcontracts. The third has been the topside for one of four Johan Sverdrup platforms, which started detailed engineering in 2015, executed as a joint venture. Experiences with the change management process, use of the CCS and utilization of BIM in the cases are used to substantiate the findings. The focus has not been to explicitly present the use in each case. In other words, the cases selected predict similar results, which can be referred to as "literal replication" in a multiple-case study (Yin, 2009). Data collection has been conducted with interviews by the author, supplemented with relevant company and project documentation. Data have primarily been gathered from 8 semi-structured interviews, including one with the engineering subcontractor on the first two case projects, with the use of interview guides, from March 2013 to April 2016. The average length of the interviews has been 1 hour 46 minutes. Each interview has been conducted with one to two interviewees in key positions. This includes Project Manager, Information Manager and Engineering Manager from the EPC contractor, in addition to Engineering Manager and System Engineering Manager from the engineering subcontractor. The stepwise-deductive-inductive (SDI) method (Tjora, 2012) has been applied to analyse the collected data. The principle of this method is to have a concept development (inductive) and subsequent quality assurance (stepwise deductive). The collected data have been transcribed and "empiric-close" coding that reflects the contents of the text 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 SDI method 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 conceptualization.

Background

Definition of change

The EPC contractor has defined change as "any unplanned, out-of-sequence design development or alteration to execution method/sequence" (Kvaerner, 2012b). An unplanned development in design can refer to what is defined as an "unintended change", where changes take place unintentionally without interference from management. They can be the result of low work quality, poor work conditions or external scope changes. Rework must be done to achieve what was intended in the original plan and specification. Alterations to the execution method or sequence can refer to "managerial changes", which are changes that take place on purpose, and are implemented through management decisions (Motawa, Anumba, Lee, & Peña-Mora, 2007; Park & Peña-Mora, 2003). An unplanned development in design can also relate to "emergent changes", which arise spontaneously and are not anticipated or intended. Alterations to the execution method or sequence can also refer to "anticipated changes" which are discovered during the project and before they actually occur (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006). Similarly, changes can be emergent, and arise from the properties itself (e.g. errors) or being initiated from the outside, and arise from improvements, enhancements or adaptations (e.g. client requests) (Jarratt et al., 2011).

Design development versus design change

According to the EPC contractor, there are two types of changes in detailed design: a "design development" initiated by the engineering team, and a "design change", initiated by the client (AkerKvaerner, 2005). A design development is linked to internal design processes and may be the consequence of maturation and development of the initial design by the engineering team. Changes are often required because parameters used in the design process change. The schedule established for a project requires design, analysis and decisions to be made partly on preliminary and unverified information and assumptions. This information is normally confirmed later in the design process, but if it turns out that parameters are outside of assumptions made, it may lead to changes to issued drawings or documents. Changes may also be the consequence of errors committed within the scope of work that needs to be corrected. A design change is a change initiated by the client, which can have a cost and schedule impact. The client can also come up with new requests or there can be changes to what the client already has requested in scope of work. In the oil and gas industry, the client refers to the owner, but is often also the operator (end user). This is opposed to the construction industry, where the client, referred to as the building owner, and the end user often are two different actors. In the latter case, the end user might initiate requests for changes in detailed design, but these go through the client (building owner) for processing and acceptance.

The two types of changes can result in four potential outcomes each, which are categorized as desired or undesired changes by the engineering team and the client, and compensated or uncompensated by the client. Compensation can either be done within the terms of the contract or through additional disbursements. This is illustrated in Table 1, and subsequently described in further detail. Light grey, grey and dark grey, respectively, indicates if an outcome is desired, should be avoided if possible or must absolutely be avoided, by the engineering team. There are two desired outcomes from both design development and design change. One of the desired outcomes from design development is not compensated for, and similarly one of the outcomes that should be avoided if possible is compensated for. This indicates that there are other aspects than only client compensation that influence if an outcome is desired.

During detailed design, the engineering team might initiate a change based on design development. If it has increased value for the client, the change can be accepted and compensated for by the client [1A]. The engineering team can initiate design improvements that have no or marginal cost and schedule implications. This can be implemented without involving the client [1B]. If the engineering team initiate a design development that has a cost and schedule impact with marginal value for the client, it can be rejected by the client. The change will then not be compensated for if implemented [1C]. Finally, design development may be the consequence of mistakes made by the engineering team, omissions, not fulfilled assumptions or lack of coordination. That is a change the engineering team must cover the consequences of [1D].

During detailed design, a design change might be initiated by the client. According to Sun and Meng (2009), client-related changes are common, especially during the design stages. These are usually caused by variations in clients' expectations and requirements, but can also be contractual changes, modifications and requirements instructed by the client. Attempts have been made to reduce the amount of design changes initiated by the client, through the use of target value design (TVD), but are not covered in this article. TVD is a management technique where the goal is to develop design in construction projects that deliver client values without increasing project cost (Russell-Smith, Lepech, Fruchter, & Littman, 2015). By making client value a driver of design, through cost, schedule and constructability as design criteria, waste can be reduced and client's expectations satisfied (Zimina, Ballard, & Pasquire, 2012). If the cost and schedule impact are compensated for, client-initiated changes can be accepted and implemented by the engineering team [2A]. There might be external factors that influence the design process. According to Sun and Meng (2009), external factors are often caused by climate conditions, site and ground conditions, or changes in government legislation and regulation. This causes a change that in most cases will be compensated for by the client due to contractual obligations. If so, the change can be implemented by the

Table 1. Types of changes and potential outcomes.

ID	Change	Engineering team	Client	Compensated
1A	Design development	Desired	Desired	Yes
1B	Design development	Desired		No
1C	Design development	Desired	Undesired	No
1D	Design development	Undesired		No
2A	Design change	Desired	Desired	Yes
2B	Design change	Desired	Undesired	Yes
2C	Design change	Undesired	Desired	Yes
2D	Design change	Undesired	Desired	No

engineering team [2B]. There might be a change initiated by the client that has cost and schedule implications, where the consequences for the engineering team can be more comprehensive than indicated. If so, the change should not be accepted, unless additional requirements from the engineering team are met [2C]. If the client initiates a change that is outside scope of work, but is not willing to compensate for the implications, it is a type of change that should not be accepted by the engineering team [2D].

A change management process in five steps

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, AkerKvaerner (2005) define change management 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, as well as the evaluation and implementation process. Streamlining the change order management process can reduce the time and cost of processing change orders (Du, El-Gafy, & Zhao, 2016). The change management process at the EPC contractor is implemented to control the design, communicate between disciplines and reduce the overall impacts of changes during project execution. This is achieved through five steps: "Identification", "Filtration", "Evaluation", "Approval" and "Implementation" (Kvaerner, 2012b).

In "Identification", the change management principles and routines are established to prevent undesired handling of changes. A list of change requests from engineering and potential changes from the client are prepared by a change manager for presentation to a Change Board. In addition to the change manager, the Change Board consists of relevant managers from engineering, planning, construction, subcontracting, procurement and contract/legal. The change manager, which is part of the engineering team, leads the Change Board and follows up decisions and further actions decided. In "Filtration", the Change Board will initially go through the list of change requests, to decide further processing. In "Evaluation", the Change Board will formally process these change requests. The consequences are assessed by different disciplines, and the results are reported back. The change manager then sums up what the consequences or impacts on the project of these change requests essentially are. This includes requesting additional documentation for a second handling of change requests if required. In "Approval", the change requests are approved or rejected by the Change Board. If necessary, client approval is needed. Progress of actions required to comply with client requirements is monitored by the change manager. Activities from the client response are closed by the discipline leads. In "Implementation", the change manager coordinates the change implementation with all relevant parties, and make sure that it is communicated and understood, and that responsible disciplines are defined and informed. Project schedule is revised with approved changes by the planning manager, when required. Handling of each change is prioritized and progress is monitored by the change manager. Relevant change documentation is updated by discipline leads.

Comparison with the construction industry

The change management process at the EPC contractor has been compared to similar processes targeted towards the construction industry, to assess the relevance. The literature review has identified a few that are similar on a principal level, despite being some clear differences. This is summarized in Figure 1, and subsequently described in further detail. The change management process at the EPC contractor is used as a benchmark. The five principal change management process steps, in addition to a sixth review step, is presented on the horizontal axis. The different sources are presented on the vertical axis. Light grey, grey and dark grey, respectively, indicate high, medium and low degree of similarity, compared to the five steps of the change management process to the EPC contractor. The figure illustrates that Jarratt et al. (2011) have the highest degree of similarity, followed by

Source	Change management process								
Kvaerner (2012b)	Identification		Filtration	Evaluation		Approval		Implement-ation	
Ibbs et al. (2001)	Promote a balanced change culture	Recognize change		Evaluate change				Implement change	Continously improve from lessons learned
Sun et al. (2006)	Start up	Identification and evaluation				Approval		Implementation and review	
Motawa et al. (2007)	Start up	Identify and evaluate				Approval and propagation			Post change
Jarratt et al. (2011)		Engineering change request raised		Identification of possible solution(s) to change request	Risk/ impact assessment of solution(s)	Selection and approval of a solution by change board		Implement-ation of solution	Review of particular change process

Figure 1. Comparison of change management processes, with the EPC contractor as benchmark.

Ibbs, Wong, and Kwak (2001), Motawa et al. (2007) and Sun et al. (2006). It also illustrates that the EPC contractor, unfortunately and in contrast to the other research, does not have a corresponding last step that focuses on review of the process and learning from experiences.

Ibbs et al. (2001) have described a project change management system (CMS), a process model based on five principles. In the first, "Promote a balanced change culture", the focus is to communicate and document critical success factors. The second, "Recognize change", is about identifying and describing potential changes, categorize the changes as required or elective, and assess potential impacts on cost, schedule and organization. The third, "Evaluate change", is about defining priority, analysing and defining impacts, and authorizing or stop/deny changes. Approval is done through an authorization by upper management. Acceptance of design changes from the client is not mentioned in the CMS. "Implement change" is about implementing and receiving final change approval, communicating and documenting change decisions, and monitor implementation. "Continuously improve from lessons learned" is about performing an evaluation, take corrective actions, comparing to initial objectives and incorporating lessons learned.

Sun et al. (2006) have described a change management process model in four stages. The first, "Start up", prepares the engineering team for effective change management, including team building, clarification of roles and responsibilities, and verifying processes and procedures. The second, "Identification and evaluation", seeks to identify potential changes and evaluate these to assist with the decision-making process. In the third, "Approval", the chosen change option needs to be approved. Approval is done by an appropriate member of the team, usually the project manager, or by the client, before it can be implemented. In the last, "Implementation and review", the change is approved and communicated to all affected team members. If necessary, the schedule is adjusted. After the implementation, the engineering team conducts a review and lessons learned from the change event.

Similarly, Motawa et al. (2007) have introduced a change process model in four sections. The first, "Start up", defines requirements for effective project management. The second, "Identify and evaluate", identifies changes and those affected or involved in decision process, and evaluate change options. As part of evaluation, changes are categorized in minor changes, changes that do not need client approval, and all other changes. The first and second categories go directly to implementation. In the third, "Approval and propagation", the client reviews potential changes. Estimation of cost and time (schedule) by the project team is crucial for the outcome. If approved, the engineering team implements changes. Minor changes or changes that do not need client approval are also implemented. In the last, "Post change", the focus is on finding a solution to potential disputes on the resolutions from the client.

Jarratt et al. (2011) have introduced an engineering change process in six steps. In the first, "Engineering change request raised", the starting point is a request for change, using standard forms. The reason, priority, type and who is affected are outlined. No routines for change handling are established. In the second, "Identification of possible solution(s) to change request", potential solutions to change requests are identified. In the third, "Risk/impact assessment of solution(s)", the impact of implementation is assessed. In the fourth, "Selection and approval of a solution by change board", a solution has been selected. An Engineering Change Board, which consists of middle to senior ranking staff from key functions, reviews the request for change, including cost–benefit, and approves for implementation. There are no activities towards client approval. In the fifth, "Implementation of solution", the engineering change is implemented. In the final, "Review of particular change process", the change is reviewed to see if intentions were fulfilled and if there were any lessons learned for future change processes.

Introducing a CCS

One of the most effective methods to deal with change is to develop an efficient change management system (Zhao, Lv, Zuo, & Zillante, 2009). The EPC contractor has developed a CCS, which is a system to store, control, report and follow up project changes and deviations. The CCS adapts the change management process towards project execution (Kvaerner, 2012b). The purpose of the CCS is to support efficient change processing, with functionality to report, follow-up and archive changes in projects. The CCS is developed with a web interface and built on an Oracle database (Kvaerner, 2012a). Based on the CCS and collected and analysed data from the research, the author has developed a flowchart that visualizes the process from identification to implementation

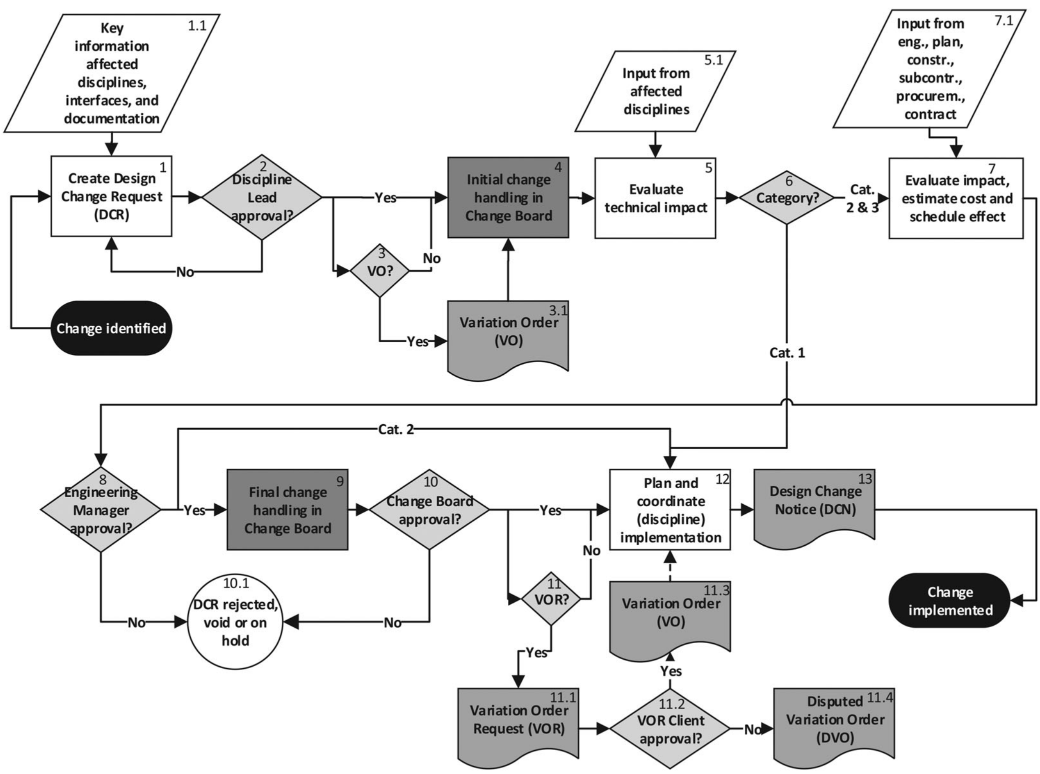

Figure 2. Principal steps in a CCS.

of a change. This is illustrated in Figure 2, and subsequently described in further detail. The focus has been to cover the principal parts of the CCS in a sequential manner, at a level that corresponds with the five steps in the change management process.

"Identification": A potential change in detailed design is identified with a design change request (DCR). For changes that occur early in detailed design, before the design is frozen, it may not be necessary to make a DCR, especially if the change does not affect any other disciplines. A DCR corresponds with a "change order", which can be defined as change to original plans, specifications or other contract documents, as well as a change in cost (Charoenngam, Coquinco, & Hadikusumo, 2003). It is always a discipline that owns the DCR, either because that discipline detected or was assigned to the change. The DCR is registered in the CCS with a name and an assigned number by the initiating discipline, which also fill out initial data. The DCR can be identified with a tag number, which allows a direct routing to the relevant part of the building information model[4] [1]. All relevant key information about the DCR, including affected disciplines, is stored in the CCS as general information. The responsible persons for discipline input and relevant interfaces are identified. Excerpts from the building information model and other documentation, that will further describe the change or its consequences, can be added to the DCR in the CCS [1.1]. The DCR shall then be forwarded to the discipline lead for approval [2]. There might be a design change initiated by the client, received as a variation order (VO), with instructions to perform a change [3]. When a VO is issued, it must be prepared for presentation to the Change Board. A VO is not normally challenged. The reason is that the EPC contractor, through the normal offshore contracts, is obliged to implement a change instruction from the client immediately and prior to reaching an agreement of cost and schedule impact. This is agreed later and on a commercial basis [3.1]. Once the VO is accepted, it is added to the current plan, which then can be updated in the next baseline revision.

"Filtration": If the DCR is approved by the discipline lead, it will be presented to the Change Board. The Change Board will meet on a regular basis, often weekly or bi-weekly, and will follow up changes or proposed changes. The Change Board decides whether the DCR should be approved for evaluation. If so, the Change Board needs to see the consequences and which disciplines are affected. The Change Board may reject the DCR. If so, the process stops before other disciplines are involved [4].

"Evaluation": The Change Board proceeds to initiate impact evaluation. It becomes an action in the CCS to get input on impact from affected disciplines. The technical impact of the DCR is evaluated [5]. All affected disciplines give input to the DCR in the CCS, including plan and cost information, risk aspects, engineering-related data affected by the change, and the type of documentation the change objects impacts. BIM is used to identify consequences for the disciplines [5.1]. When the disciplines have completed their input, the status is updated, and a notification to those responsible for the DCR is sent, using the CCS. Available statuses for the DCR in the CCS are "Initiate", "Recommend", "Evaluate", "Decide" and "Complete" (AkerSolutions, 2008). A fundamental rule in engineering is the principle of making a decision at the lowest possible responsible level. Efficient change handling can therefore be achieved by categorizing change requests according to their estimated impact. Category 1 changes have no schedule or cost impact, do not affect others, and can be approved by the discipline lead. This will typically be discipline-internal changes. Category 2 changes have minor schedule or cost impact, do not affect others, and can be approved by the engineering manager. Category 3 changes have significant impact on cost and schedule, affect others, and must be approved by the Change Board (AkerKvaerner, 2005) [6]. If category 1, the DCR will go directly to the relevant discipline for planning and coordinating implementation [12]. When category 2 or 3, the DCR must go through a multi-discipline evaluation. The various disciplines give input to plan and cost in the CCS. These are evaluated and summarized. A challenge is to appraise cumulative effects of having several changes. This will often have a schedule impact [7]. The DCR can influence the project on several dimensions. It is therefore important to get input from all relevant managers in the Change Board to evaluate the impact [7.1]. The information on the consequences, the need for rework and the hours needed is used by the engineering manager to evaluate category 2 changes and either reject or approve the DCR [8]. If approved, category 2 changes will go directly to the relevant disciplines for planning and coordinating implementation [12]. For category 3 changes, the consequences are described in the CCS and reported back, so that the Change Board can evaluate the impacts of the change [9].

"Approval": The Change Board now has the necessary information, and can decide if the DCR is going to be approved for implementation [10]. In situations where not all consequences are identified, the DCR must be put on hold. If the DCR, for some reason, is no longer relevant, it can be voided. Consequences if the DCR is not implemented shall be listed in the CCS [10.1]. The change can be initiated as a design development by the engineering team or a design change by the client. If a design development affects scope of work, it needs approval from the client to be compensated. A variation order request (VOR) is created. If a VO has been received from the client, with a design change that is not in accordance with the scope of work, there might be additional clarifications or decisions from the engineering team that must be met in order to be fully compensated. A VOR is then created [11]. The change manager has the responsibility to establish a VOR, which includes creating key information, generating cost and schedule estimates, and adding relevant documentation in the CCS. Relevant data from the DCR are copied over to the VOR. When complete, the VOR must be approved by project management [11.1]. The VOR is sent to the client for approval. If engineering is subcontracted, the VOR from the engineering team will go to the client through the EPC contractor, which is the contractual part to the client. If engineering is contracted separately, the VOR will go directly to the client. A poorly developed VOR provides small chances to get an acceptance and receive a VO from the client [11.2]. If the client approves the VOR, a VO is issued [11.3]. The VO will be used as input to planning and coordination [12]. If the client rejects the VOR, a disputed variation order (DVO) is issued [11.4].

"Implementation": If there is a decision to implement the DCR, it is planned and coordinated by affected disciplines [12]. When the information to the DCR is revised, the status can be updated in the CCS. A design change notice (DCN), which is an instruction for implementation, is created in the CCS, on the basis of a DCR. The DCN will be issued by the owning discipline. It is a single-discipline instruction, and comes in the form of documents, drawings and instructions [13].

Comparison with the construction industry

There have been several attempts to create change management systems for the construction industry, but the literature review indicates that few are similar to the structure and scope of the CCS. Of the change management processes presented earlier, two have corresponding change management systems. Sun et al. (2006) have presented a change management toolkit, to support their change management process model. In addition to a standard procedure to identify, evaluate, approve and implement project changes, it consists of 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. Motawa et al. (2007) have presented an integrated change management system, to support their change process model. It is based on system dynamics and consists of two main functions. The first is to predict the level of stability through the probability of change occurrence. The second is to simulate potential iterations that might occur during implementation of a change. The result of the first function is used as a basis to run the simulation in the second function. 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 in change management

It is difficult to pick up and register all changes in a project. When changes are detected, it is often demanding to identify all consequences. Engineering teams often rely on subjective expert opinions, manual analyses and comparisons of drawings. This is due to the lack of competence and use of BIM software for tracking changes between different revisions of building information models and effectively presenting the results (Pilehchian, Staub-French, & Nepal, 2015). If the proper BIM software is used, changes will most likely be identified in time and not end up as clashes that need to be cleaned up. With BIM-based review software, practitioners can, for instance, aggregate, simulate and analyse building information models, help track the history of changes between revisions, identify and analyse clashes, detect deficiency and do quantification take-off (Autodesk, 2016; Solibri, 2016). When evaluating a DCR, BIM is used by the disciplines to assess if it is feasible and identify the downstream consequences of the change. An extract from the building information model can illustrate what the change is all about and who is affected. The disciplines can go directly into the building information model and see what they should do with their part of the design that is affected by this change. If there is a client-affected change, the cost and schedule impact must also be identified. According to Pilehchian et al. (2015), cost and schedule impacts depend on the progress in design of affected objects. To determine the acceptable timing of such changes, important project data such as schedule and status of objects should be integrated into the building information model.

The relation between the CCS and the use of BIM is based on what is frozen. When using BIM in detailed design, objects are gradually frozen, as the disciplines reach the relevant quality levels at the corresponding milestones and fulfil the requirements to update the object status accordingly, based on the PEM. Four main status levels on objects in detailed design are defined. These are S1 "Preliminary", S2 "Released for IDC", S3 "Frozen" and S4 "Detail design completed". Corresponding checklists with control questions for each discipline must be fulfilled, to be able to obtain a desired status level. The status of the objects in the building information model are updated to "Frozen" when comments from interdisciplinary design control (IDC) are implemented, and interfaces towards other objects and disciplines are clarified. Frozen objects can be further developed, as long as they do not affect others. Object status is crucial when making decisions about the proper timing of a change to reduce its impact. Object status can be illustrated with a colour code, so that maturity and quality can be visualized directly in the building information model, and support the disciplines to identify what is still being developed and what is frozen (see Figure 3). This helps the disciplines in the engineering team to not change anything on the design where objects are frozen. Once any of the disciplines need to change part of the design that is frozen, or the client need to change something that affects the design that is frozen, the changes must be managed, and then the CCS is initiated.

Discussion

This paper has introduced a change management process, as defined by the EPC contractor, and related it to research that describes similar processes for the construction industry. The comparison indicates that the change process by Jarratt et al. (2011), which also includes the use of a Change Board, is the most similar. The change management processes from Ibbs et al. (2001), Sun et al. (2006) and Jarratt et al. (2011) include a last step, with focus on evaluating the process and identifying lessons learned. This could preferably be added as a fifth step in the change management process at the EPC contractor. This step could also include follow-up on the changes, to verify that these are implemented as planned.

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

Figure 3. Status levels on objects used in detailed design (AkerSolutions, 2009).

This would give valuable input to the "Identification" step, where the change management principles and routines for the project are established. Despite not being part of the change management process, the case projects indicate that the EPC contractor has a review process to learn from experiences. For each project, the change manager writes an experience report, where important changes and how these have been processed in the project are identified. There are also joint meetings and forums between change managers across ongoing projects, to share best practices. According to the EPC contractor, a lessons-learned process is also in place during project start-up, where lessons from previous projects are made available, and the CCS is open for review.

According to the EPC contractor, the CCS is one of the most important systems in project execution besides the technical applications. It is an efficient way of communicating a change in the organization, and makes different stakeholders aware and able to plan their work accordingly. The use of the CCS follows the principles of the five steps in the change management process (identification, filtration, evaluation, approval and implementation). DCRs are differentiated in three categories, mainly based on their impact on cost and schedule. By categorizing DCRs, these can be evaluated and accepted at different management levels, which supports a more efficient processing. Experiences from case projects indicate that projects using the CCS without actively categorizing DCRs, ended up having a more circumstantial process, because all DCRs had to go through full evaluation and approval in the Change Board. Having a combination of a Change Board and categorization can decrease transaction cost, and increase action efficiency, and reduce the time it takes from a change is detected until it is solved.

Costs are added up when changes have not been detected in time. Changes that occur late on in the design process also affect far more actors. The cost of changes in design increases towards the end of detailed design. Inversely, the ability to impact cost and schedule decreases. Using BIM increases detailing of the design earlier in detailed design, which gives a better basis to evaluate impact and consequences of changes in design, while the cost of changes is still low and the ability to impact cost and schedule is still high. Objects in the building information model are gradually frozen in detailed design, once requirements to reach the desired quality levels, as defined in the PEM, are achieved. When objects are frozen and still must be changed, the changes must be managed and the CCS is initiated. Status on objects in the building information model can identify what is frozen. This can be visualized using colour codes. The CCS should therefore be used in detailed design from the point where objects are being gradually frozen until the design is frozen and drawings from the building information model are issued for construction.

Jarratt et al. (2011) state that tools and methods that support 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 change management process and the use of the CCS combined with the utilization of BIM, to evaluate change requests, addresses and combine both these groups. The reason for developing the flowchart and the corresponding description in this paper is to illustrate and explain the most important steps in the CCS, so that it can be used as a basis to develop a similar system for use in detailed design in construction projects. The CCS, which is described and illustrated, should be relevant because it supports a change management process based on the same principles as the research on corresponding processes developed for the construction industry. The findings are based on case projects executed as EPC contracts (design-build). According to the engineering subcontractor on two of the case projects, the applicability of the CCS in design is the same when engineering and procurement, and construction are contracted separately by the client. This corresponds to a design-bid-build contract in the construction industry.

Conclusion

This paper has introduced a change management process in five steps, developed by an EPC contractor for use in offshore and onshore projects in the oil and gas industry. As presented, the change management process has many similarities with corresponding processes in the construction industry, which increases relevance and applicability. This paper has assessed how changes in detailed design can be handled using a CCS. A flowchart has been developed and the principles of how the main steps in the CCS works have been presented, from a change is identified, with a DCR, to a change is implemented, with a DCN. Based on the findings, a combination of four central aspects differentiates the change management process with the use of the CCS, compared to existing research, and highlights the benefits of introducing the CCS towards the construction industry. The first is how a Change Board through the CCS efficiently coordinate input from affected disciplines, evaluate impact and approve implementation. Consisting of a change manager, who leads and facilitates, and other relevant managers from key functions, the Change Board has a unique composition for a holistic processing of each DCR. The second is how change requests are categorized, based on their cost and schedule impact, and effect on other disciplines, to allow efficient processing. The third is the focus on a formal approval process towards the client, so that design changes from the client are received, evaluated and responded properly, and that changes based on design development from the engineering team are documented and efficiently communicated to the client. The last is how BIM can be used to assess if the change is feasible and identify the downstream consequences of changes in design. Based on the developed flowchart and corresponding description, further research will focus on developing a mock-up of a CCS, a prototype with key functionality of the system, as the first step towards testing and developing a similar system for the construction industry.

Notes

1. 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, Sher, & Williams, 2012).
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 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, 2012c).
4. A building information model can be defined as a digitally constructed virtual model of a building. When completed, the building information model contains precise geometry and relevant data needed to support the design, procurement, fabrication and construction activities required to realize the building (Azhar, 2011).

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References

AkerKvaerner. (2005). *Change control methodology manual – change handling*. Retrieved from Kvaerner.
AkerSolutions. (2008). *CCS user manual*. Retrieved from Kvaerner.
AkerSolutions. (2009). *PEM NB terms/definitions and abbreviations*. Retrieved from Kvaerner.
Autodesk. (2016). *Autodesk Navisworks*. Retrieved from http://www.autodesk.com/products/navisworks/features/all/gallery-view
Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252.

Charoenngam, C., Coquinco, S. T., & Hadikusumo, B. H. W. (2003). Web-based application for managing change orders in construction projects. *Construction Innovation: Information, Process, Management*, *3*(4), 197–215. doi:10.1108/14714170310814936

Du, J., El-Gafy, M., & Zhao, D. (2016). Optimization of change order management process with object-oriented discrete event simulation: Case study. *Journal of Construction Engineering and Management 142*(4). doi:10.1061/(ASCE)CO.1943-7862.0001092

Halkier, B. (2011). Methodological practicalities in analytical generalization. *Qualitative Inquiry*, *17*(9), 787–797.

Ibbs, C. W., Wong, C. K., & Kwak, Y. H. (2001). Project change management system. *Journal of Management in Engineering*, *17*(3), 159–165.

Isaac, S., & Navon, R. (2009). Modeling building projects as a basis for change control. *Automation in Construction*, *18*(5), 656–664. doi:10.1016/j.autcon.2009.01.001

Jarratt, T., Eckert, C. M., Caldwell, N., & Clarkson, P. J. (2011). Engineering change: An overview and perspective on the literature. *Research in Engineering Design*, *22*(2), 103–124.

Kvaerner. (2012a). *Application factsheets*. Retrieved from Kvaerner.

Kvaerner. (2012b). *Change management*. Retrieved from Kvaerner.

Kvaerner. (2012c). *Kvaerner PEM method statement*. Retrieved from Kvaerner.

Motawa, I. A., Anumba, C. J., Lee, S., & Peña-Mora, F. (2007). An integrated system for change management in construction. *Automation in Construction*, *16*(3), 368–377. doi:10.1016/j.autcon.2006.07.005

Park, M., & Peña-Mora, F. (2003). Dynamic change management for construction: Introducing the change cycle into model-based project management. *System Dynamics Review*, *19*(3), 213–242. doi:10.1002/sdr.273

Pilehchian, B., Staub-French, S., & Nepal, M. P. (2015). A conceptual approach to track design changes within a multi-disciplinary building information modeling environment. *Canadian Journal of Civil Engineering*, *42*(2), 139–152.

Russell-Smith, S. V., Lepech, M. D., Fruchter, R., & Littman, A. (2015). Impact of progressive sustainable target value assessment on building design decisions. *Building and Environment*, *85*, 52–60.

Shen, W., Hao, Q., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., … Xue, H. (2010). Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review. *Advanced Engineering Informatics*, *24*(2), 196–207. doi:10.1016/j.aei.2009.09.001

Solibri. (2016). *Solibri Model Checker*. Retrieved from http://www.solibri.com/products/solibri-model-checker/

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Architectural Engineering and Design Management*, *8*(2), 120–142.

Sun, M., Fleming, A., Senaratne, S., Motawa, I., & Yeoh, M. L. (2006). A change management toolkit for construction projects. *Architectural Engineering and Design Management*, *2*(4), 261–271.

Sun, M., & Meng, X. (2009). Taxonomy for change causes and effects in construction projects. *International Journal of Project Management*, *27*(6), 560–572. doi:10.1016/j.ijproman.2008.10.005

Tjora, A. H. (2012). *Kvalitative forskningsmetoder i praksis* [Qualitative research methods in practice]. Oslo: Gyldendal akademisk.

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA.: Sage.

Zhao, Z. Y., Lv, Q. L., Zuo, J., & Zillante, G. (2009). Prediction system for change management in construction project. *Journal of Construction Engineering and Management*, *136*(6), 659–669.

Zimina, D., Ballard, G., & Pasquire, C. (2012). Target value design: Using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics*, *30*(5), 383–398.