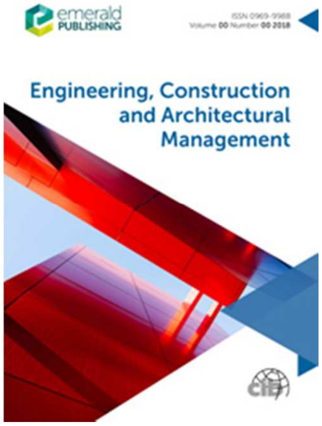

A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects

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Abstract:	

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Abstract

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

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

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

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

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

Introduction

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

In large projects in the oil and gas industry, there has over the years been an increased utilization of a 3D design environment, which is a multidiscipline and object-based 3D design (Kvaerner, 2012a). This corresponds to building information modeling (BIM) in the construction industry. A Norwegian engineering, procurement and construction (EPC) contractor (hereinafter called EPC contractor), and a Norwegian engineering contractor (hereinafter called engineering contractor 1) early started focusing on how they could report progress in detail engineering and not only construction. This was based on their experience with visualizing and simulating progress in construction using a 3D design environment (hereinafter called BIM).They started to set statuses on objects that had reached a certain level of quality in the 3D models, corresponding to building information models in the construction industry. A building information model can be defined as an "accurate virtual model of a building constructed digitally [that] when completed […] contains precise geometry and relevant data needed to […] realize the building" (Eastman *et al.*, 2008, p. 1). The reason was to try to move away from estimates, sometimes guesstimates, on how far each discipline had come, when reporting progress towards an engineering schedule. When a discipline had completed a defined work, the objects were given relevant statuses. Eventually the EPC contractor could extract statuses directly from the 3D models (hereinafter called building information models), which formed the basis for extracting progress from the building information models in detail engineering and the subsequent connection towards an engineering schedule.

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

Background

BIM

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

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

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

Project execution model

The construction industry is a knowledge-intensive and experience-based industry (Yang *et al.*, 2013). With the rapid BIM adoption, the industry is undergoing transition to a new era of digital information. Still, the dominant form of knowledge on project execution still exists in the form of tacit knowledge (Nepal and Staub-French, 2016). Knowledge gained by a project team during a project is often not retained and used on future projects. A crucial step for counteracting this is the conversion of tacit knowledge to explicit knowledge, where only explicit knowledge can be integrated in an organizational knowledge base. This transformation can be supported by knowledge management (Lindner and Wald, 2011). Knowledge management can be defined as “the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage” (Carrillo and Chinowsky, 2006, p. 2), and is critical for process improvement. When implementing knowledge management, there can be several barriers, such as lack of standard processes, poor organizational culture, insufficient funding, employee resistance and poor IT infrastructure (Yang *et al.*, 2013). According to Carrillo and Chinowsky (2006), knowledge management systems can be implemented to facilitate the capture, access, and reuse of information and knowledge. Effective knowledge management systems have the ability to communicate and preserve knowledge across all stages of a construction project (Deshpande *et al.*, 2014). The dominant type of knowledge management system that has been used in practice, is what Newell (2015) calls repository system, which is based on facilitating the sharing of explicit knowledge. To succeed, the repository must contain knowledge useful for employees looking for answers and solutions in execution of projects. The repository must not only contain useful knowledge but the knowledge must be intuitive and easy to find.

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

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

The PEM, as developed by the EPC contractor and engineering contractor 1, is used as a basis for this research. It is based on the knowledge areas in PMBOK (PMI, 2013), especially the Project Integration Management knowledge area, with focus on actions that are crucial to a controlled project execution. The PEM is structured as a three-level pyramid, to clearly define the methodology, simplify navigation and ensure consistency, with a strategic level on top, followed by a control level and execution level (see Figure 1). The strategic level describes the life cycle of a project, split into phases with requirements for each phase. All phases are divided into multidiscipline stages, and the control level describes the stages to each of the phases, where each stage is ending up in a milestone. This is similar to the principles of a stage-gate process (Cooper, 1990). Objectives and focus areas for each stage and milestone requirements are also defined. The strategic and control level are more general and should be used in all projects. What differentiates the PEM compared to other knowledge management systems and stage-gate models is the execution level. The execution level describes all work processes and activities to management and execution disciplines. This level is much more comprehensive than the first two. The extent of use will depend on the type, size and complexity of the project (Kvaerner, 2012b).

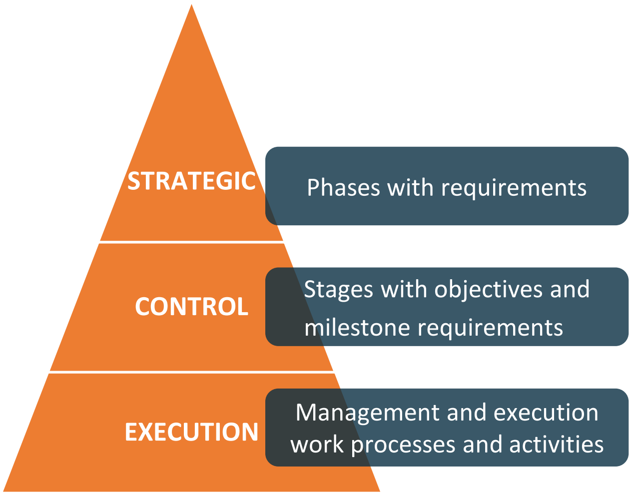


Figure 1: The three levels of the PEM. Adapted from Kvaerner (2012b)

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

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

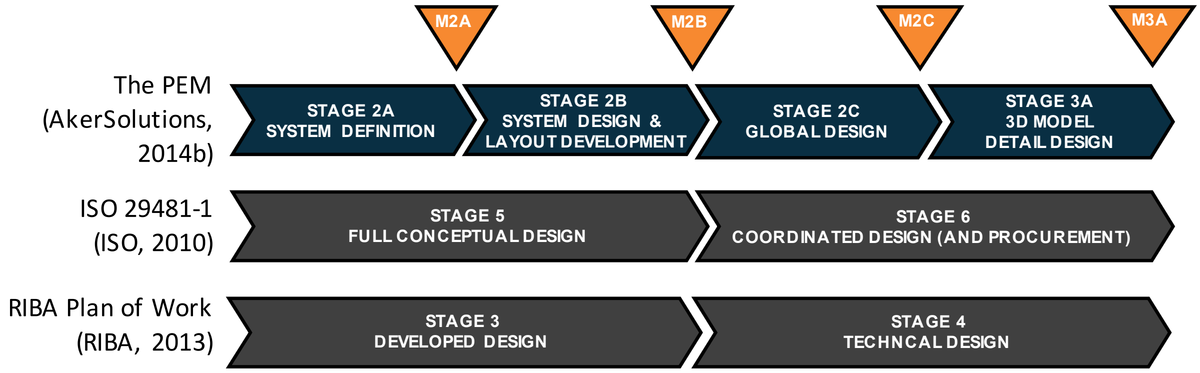


Figure 2: Stages of detail engineering in the PEM, compared to the construction industry

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

Research method

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

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

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

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

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

Report progress in detail engineering using BIM

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

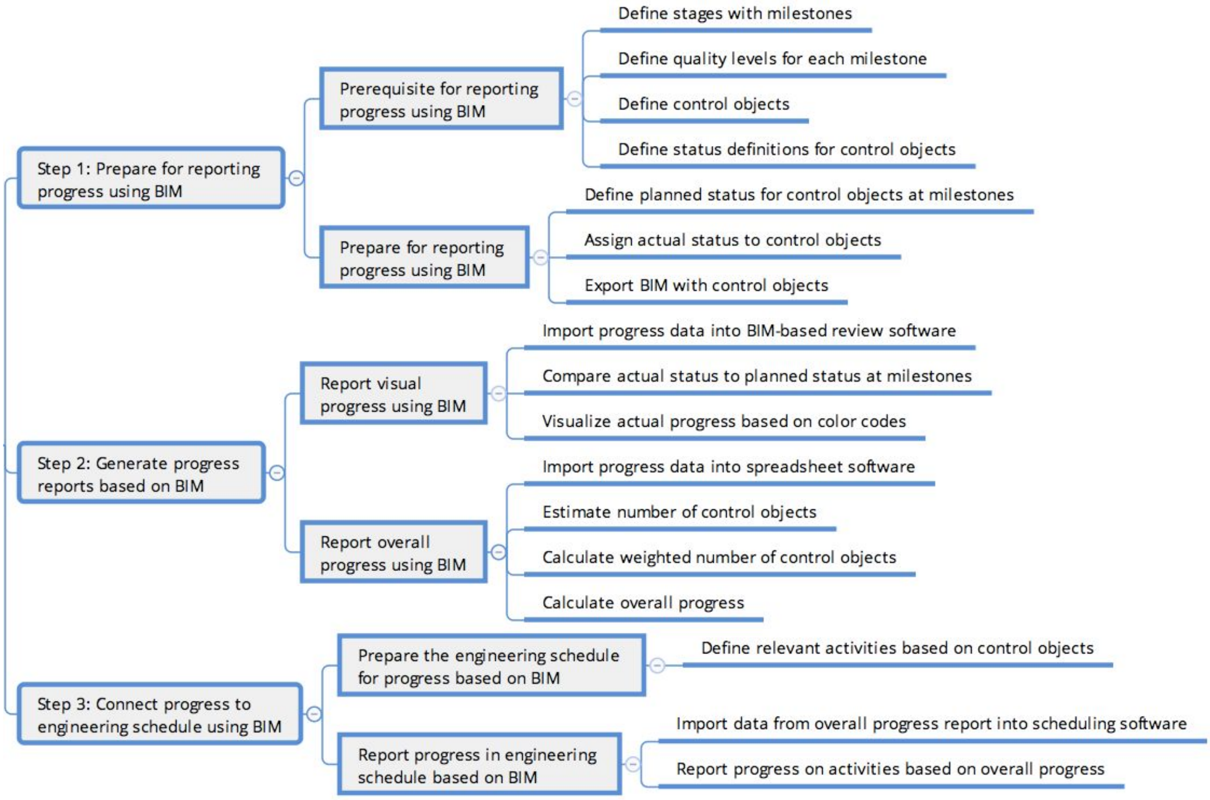
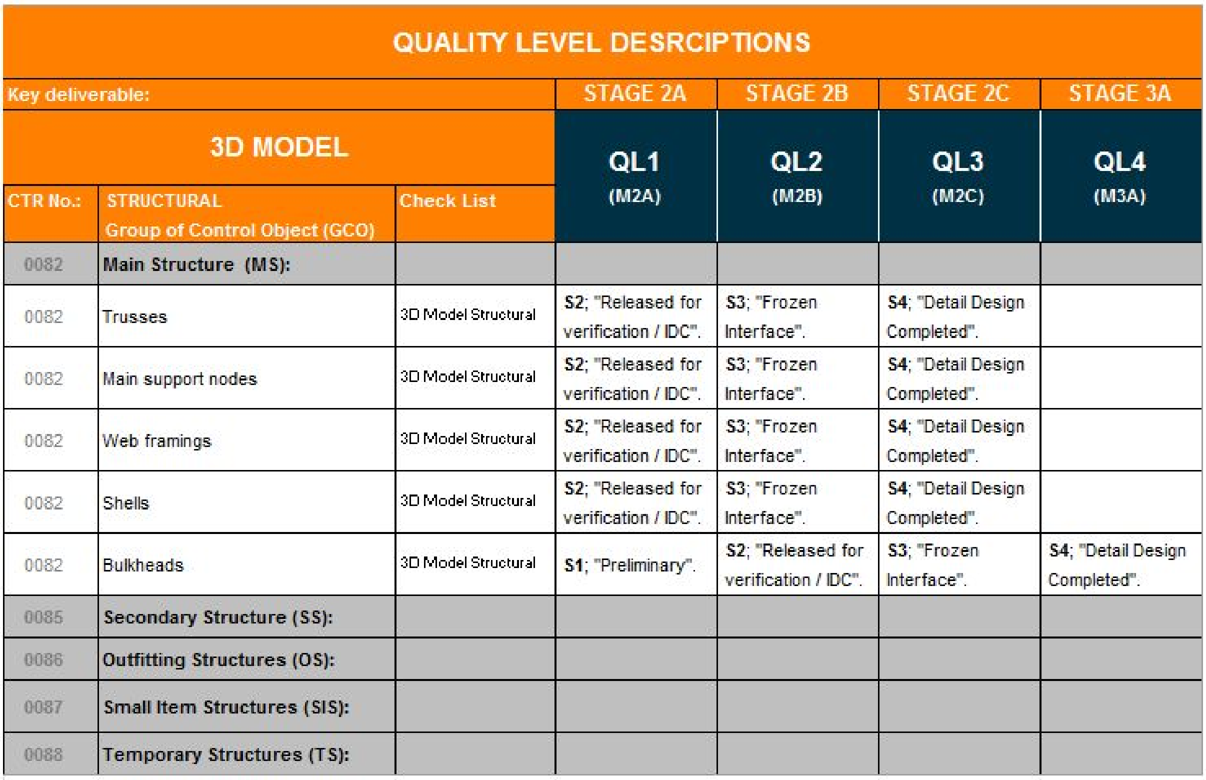


Figure 3: Using BIM to report progress in detail engineering in three steps

Step 1: Prepare for reporting progress using BIM

Prerequisite for reporting progress using BIM

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



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

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

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

The third principle is that the degree of completion each control object should have to achieve a certain quality level at each milestone, are defined through status requirements. It is possible to get control of the engineering deliverables using statuses that defines quality and maturity of the control objects in the building information models. The status definitions, which in the PEM consist of a status code, name and description, are common for all control objects and all disciplines (AkerSolutions, 2013). According to the PEM, there are four main statuses on control objects in building information models in detail engineering (see Figure 4). The statuses define the grade of completeness for a control object at the various milestones. To illustrate this, a small red circle can symbolize the degree of accuracy around the placement on the surrounding circle. The first is status S1, where the control object still has a preliminary location. The next is status S2, where the shape and location is set for interdisciplinary design control (IDC). The next is status S3, where the location of the control object and interface to other disciplines are frozen. This is a critical status for all control objects. When frozen, the shape and location of control objects in a building information model, and all interfaces towards other control objects should, by definition, not be changed. The last is status S4, where the final detailing of the control objects are finished and deliverables are ready to be issued for construction (IFC) (AkerSolutions, 2013).

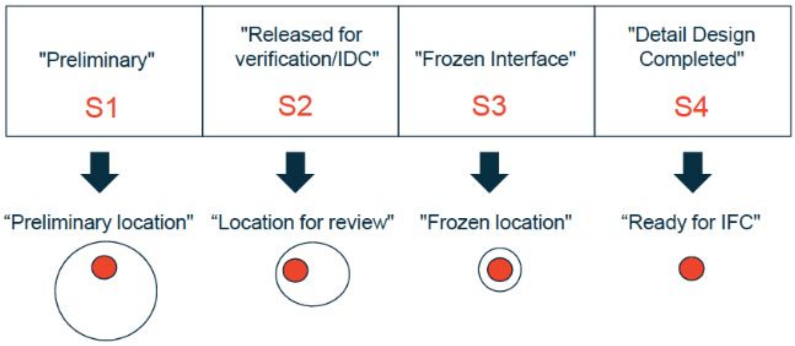


Figure 4: Object placement related to status definitions (AkerSolutions, 2014a)

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

Prepare for reporting progress using BIM

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

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

Step 2: Generate progress report based on BIM

Report visual progress using BIM

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

By assigning a color code to each status, the control objects in the building information models can visualize the quality and maturity directly, and support the disciplines in identifying what is still being developed and what is frozen. According to Sacks *et al.* (2009) visualization of process status is needed and should be displayed in a manner that can be readily understood by all, regardless of their technical knowledge. Building information models with color coding, used as an added feature of multidiscipline design reviews, is very useful for seeing statuses on the control objects and coordinating where the disciplines are and what is missing. Similarly, Sacks *et al.* (2010b) defined the state of readiness of a work package or a task, measured through maturity. The maturity index was displayed using color-coded symbols on task icons. Chen and Luo (2014), described how the building information models could visualize quality status in construction with different color codes, grouped in two; before or after inspection was performed. Common for these and similar research is that the primary focus is on construction, and not detail engineering.

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

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

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

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

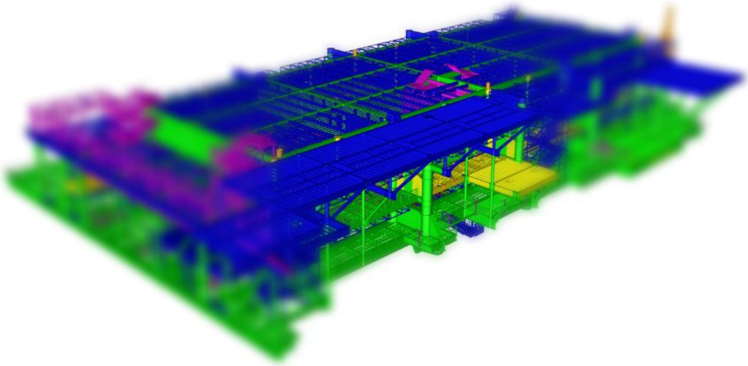


Figure 5: Extract of a color coded version of a building information model for the structural discipline (K2JV, 2016a)

Report overall progress using BIM

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

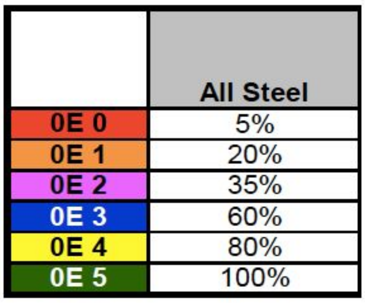
In the beginning of a project, each discipline should spend time to establish where they are going, to be able to plan and measure progress. This requires a realistic number of control objects to be evaluated, i.e. number of modelled and estimate of unmodeled control objects. The report is only as good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

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

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

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

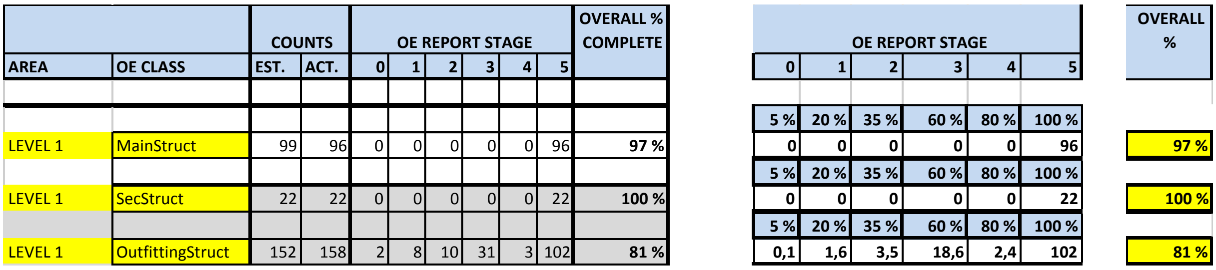
At a given cut-off date, there is a certain distribution of control objects with different statuses (S0-S5) within each control object group for each level. There is also estimated and actual number of control objects for each control object group, for each level. With these numbers in place, the overall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



	All Steel
0E 0	5%
0E 1	20%
0E 2	35%
0E 3	60%
0E 4	80%
0E 5	100%

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

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



		COUNTS		OE REPORT STAGE						OVERALL % COMPLETE	OE REPORT STAGE						OVERALL %
AREA	OE CLASS	EST.	ACT.	0	1	2	3	4	5		0	1	2	3	4	5	
											5 %	20 %	35 %	60 %	80 %	100 %	
LEVEL 1	MainStruct	99	96	0	0	0	0	0	96	97 %	0	0	0	0	0	96	97 %
											5 %	20 %	35 %	60 %	80 %	100 %	
LEVEL 1	SecStruct	22	22	0	0	0	0	0	22	100 %	0	0	0	0	0	22	100 %
											5 %	20 %	35 %	60 %	80 %	100 %	
LEVEL 1	OutfittingStruct	152	158	2	8	10	31	3	102	81 %	0,1	1,6	3,5	18,6	2,4	102	81 %

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

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

Step 3: Connect progress to engineering schedule using BIM

Prepare the engineering schedule for progress based on BIM

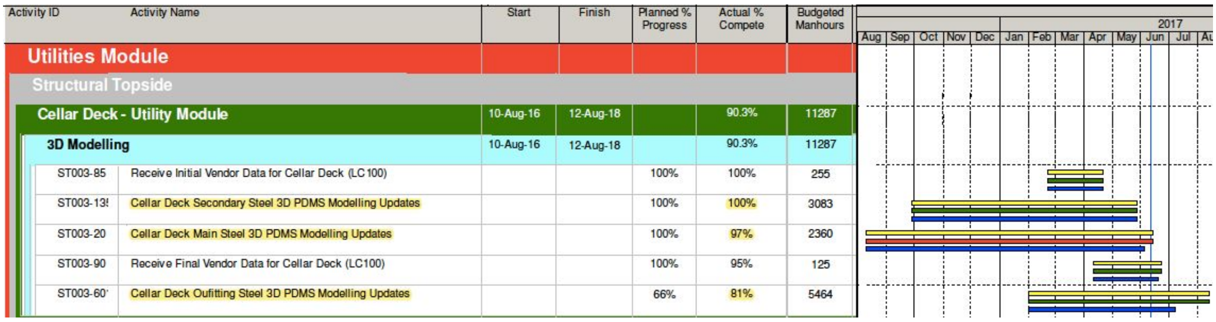
A prerequisite for connecting progress based on BIM to an engineering schedule is that the schedule consists of activities that can be related to progress data from the building information models, either indirectly or directly. Indirectly, activities can be defined in a way so that building information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

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

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

Report progress in engineering schedule based on BIM

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



Activity ID	Activity Name	Start	Finish	Planned % Progress	Actual % Compete	Budgeted Manhours
Utilities Module						
Structural Topside						
Cellar Deck - Utility Module		10-Aug-16	12-Aug-18		90.3%	11287
3D Modelling		10-Aug-16	12-Aug-18		90.3%	11287
ST003-85	Receive Initial Vendor Data for Cellar Deck (LC100)			100%	100%	255
ST003-13	Cellar Deck Secondary Steel 3D PDMS Modelling Updates			100%	100%	3083
ST003-20	Cellar Deck Main Steel 3D PDMS Modelling Updates			100%	97%	2360
ST003-90	Receive Final Vendor Data for Cellar Deck (LC100)			100%	95%	125
ST003-60	Cellar Deck Oufitting Steel 3D PDMS Modelling Updates			66%	81%	5464

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

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

Discussion

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

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

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

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

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

ENGINEERING STATUS DEFINITIONS		
STATUS	**NAME**	**DESCRIPTION**
S0	Defined	The control object is defined in the model. The shape can be as simple as a cube.
S1	Preliminary	Control object modelled with simplified shape based on preliminary design from previous stage and estimated information.
S2	Released for verification/ IDC	Detailed shape with outer dimensions and location approved by own discipline.
S3	Frozen interface	Control object completed with final shape and location. Verification/IDC comments implemented. Interfaces towards other control objects and other disciplines frozen.
S4	Detail design completed	Detail design of control object completed and approved for construction. Detailing shall not affect interfaces to other disciplines and control objects.
S5	Issued for construction	All necessary prefabrication, installation and commissioning information added.
S6	As-built	Relevant as-built information implemented

LEVEL OF DETAIL/DEVELOPMENT (LOD) DEFINITIONS	
LOD	**DESCRIPTION**
LOD 100	The modelling object is represented as a symbol or generic representation.
LOD 200	The modelling object is represented as a generic object with approximate quantities, size, shape, location and orientation.
LOD 300	The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation.
LOD 350	The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation, and interfaces with other building systems (disciplines).
LOD 400	The modelling object is represented as a specific object in terms of quantity, size, shape, location and orientation, with detailing, fabrication, assembly and installation information.
LOD 500	LOD 500 adds field verified representation (as-built).

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

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

Conclusions

A three-step process for reporting progress in detail engineering with the use of BIM has been developed, based on experiences from projects in the oil and gas industry. This process can be used as a basis for adaption towards projects in the construction industry. The majority of the existing research related to monitoring progress using BIM relates to construction and not detail engineering. What further differentiates the three-step process from similar research is the first step, which is a prerequisite for the last two. In the first step, principles from a PEM are applied. What differentiates the use of a PEM compared to knowledge management systems and stage-gate models is the execution level. Here, control objects and status definitions are defined for each discipline, and related to quality levels, which are crucial for being able to report progress using BIM. In the second step, both visual and overall progress can be reported using BIM. By adding color codes to status definitions, progress can be reported visually, through control objects in the building information models. This makes it possible to see the maturity and quality of the building information models directly, including what is frozen and should by definition not be changed. Status is both quality and quantity. Overall progress can be reported through aggregating the actual number of control objects and statuses on these, compared to an estimated number of control objects. By weighting the number of control objects, the calculation of the overall progress can be more accurate. To connect the overall progress towards an engineering schedule in the third step, activities in the engineering schedule are defined based on control objects, so that progress can be reported directly from the building information models. The first two steps support the first part of the research question on how progress in detail engineering can be reported using BIM. Based on the first two steps, the last step supports the last part of the research question on how progress reporting can be connected to activities in an engineering schedule.

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

AkerSolutions (2009), "PEM NB Terms / Definitions and Abbreviations", Unpublished Manuscript, Aker Solutions.

AkerSolutions (2013), "Engineering Status Descriptions", Unpublished Manuscript, Aker Solutions.

AkerSolutions (2014a), "PEM - Project Execution Model Training Course", Unpublished Manuscript, Aker Solutions.

AkerSolutions (2014b), "PEM – Project Execution Model", Unpublished Manuscript, Aker Solutions.

Autodesk. (2016), "Autodesk Navisworks". available at: http://www.autodesk.com/products/navisworks/features/all/gallery-view (accessed 13.01 2016).

Azhar, S. (2011), "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry", *Leadership and Management in Engineering,* 11**,** 241-252.

Azhar, S., Khalfan, M. and Maqsood, T. (2012), "Building information modeling (BIM): Now and beyond", *Australasian Journal of Construction Economics and Building,* 12**,** 15-28.

BIMForum (2013), "Level of Development Specification - for Building Information Models". available at: http://bimforum.org/wp-content/uploads/2013/08/2013-LOD-Specification.pdf (accessed 25.10.2017).

Bosché, F., Ahmed, M., Turkan, Y., Haas, C. T. and Haas, R. (2015), "The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components", *Automation in Construction,* 49**,** 201-213.

Bryde, D., Broquetas, M. and Volm, J. M. (2013), "The project benefits of building information modelling (BIM)", *International journal of project management,* 31**,** 971-980.

BuildingSMART. (2017), "buildingSMART - International home of openBIM". available at: http://www.buildingsmart.org/ (accessed 09.10 2017).

Carrillo, P. and Chinowsky, P. (2006), "Exploiting knowledge management: The engineering and construction perspective", *Journal of Management in Engineering,* 22**,** 2-10.

Chen, L. and Luo, H. (2014), "A BIM-based construction quality management model and its applications", *Automation in Construction,* 46**,** 64-73.

Cooper, R. G. (1990), "Stage-gate systems: a new tool for managing new products", *Business horizons,* 33**,** 44-54.

Deshpande, A., Azhar, S. and Amireddy, S. (2014), "A framework for a BIM-based knowledge management system", *Procedia Engineering,* 85**,** 113-122.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008), *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors,* Hoboken, John Wiley & Sons.

Fischer, M., Khanzode, A., Reed, D. and Ashcraft, H. W. (2017), *Integrating Project Delivery*, John Wiley & Sons.

Golparvar-Fard, M., Peña-Mora, F. and Savarese, S. (2012), "Automated progress monitoring using unordered daily construction photographs and IFC-based building information models", *Journal of Computing in Civil Engineering,* 29**,** 04014025.

Han, K. K., Cline, D. and Golparvar-Fard, M. (2015), "Formalized knowledge of construction sequencing for visual monitoring of work-in-progress via incomplete point clouds and low-LoD 4D BIMs", *Advanced Engineering Informatics,* 29**,** 889-901.

Han, K. K. and Golparvar-Fard, M. (2017), "Potential of big visual data and building information modeling for construction performance analytics: An exploratory study", *Automation in Construction,* 73**,** 184-198.

Hartmann, T., Van Meerveld, H., Vossebeld, N. and Adriaanse, A. (2012), "Aligning building information model tools and construction management methods", *Automation in construction,* 22**,** 605-613.

ISO (2010), "Building information modelling - Information delivery manual - Part 1: Methodology and format". available at: https://www.iso.org/obp/ui/#iso:std:iso:29481:-1:ed-1:v1:en (accessed 04.04.2016).

K2JV (2015), "Use of OE & Stage Build for the LQ Topsides. Statoil Johan Sverdrup Living Quarter Topside EPC", Unpublished Manuscript, K2JV.

K2JV (2016a), "JOHAN SVERDRUP K2JV STRUCTURAL PDMS OE MODEL ISO 3 VIEW – 20 June 2016", Unpublished Manuscript, K2JV.

K2JV (2016b), "K2JV Johan Sverdrup Utility Module Detail Design Engineering and Procurement Level IV Schedule", Unpublished Manuscript, K2JV.

K2JV (2016c), "Object Engineering Work Instruction - Structural", Unpublished Manuscript, K2JV.

KBR (2016), "OE overall report", Unpublished Manuscript, KBR.

Kim, C., Son, H. and Kim, C. (2013a), "Automated construction progress measurement using a 4D building information model and 3D data", *Automation in Construction,* 31**,** 75-82.

Kim, H., Anderson, K., Lee, S. and Hildreth, J. (2013b), "Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology", *Automation in Construction,* 35**,** 285-295.

Kunz, J. and Fischer, M. (2012), "Virtual design and construction: themes, case studies and implementation suggestions", *Center for Integrated Facility Engineering (CIFE), Stanford University*.

Kvaerner (2012a), "Attachment C12-B - Application Factsheets", Unpublished Manuscript, Kvaerner.

Kvaerner (2012b), "Kvaerner PEM Method Statement", Unpublished Manuscript, Kvaerner.

Kvaerner. (2014), "Kværner ASA: Kvaerner delivers Eldfisk 2/7 S topside". Kvaerner. available at: https://www.kvaerner.com/toolsmenu/Media/Press-releases/2014/Kvarner-ASA-Kvaerner-delivers-Eldfisk-27-S-topside/ (accessed 19.05 2017).

Kvaerner. (2015a), "Kværner ASA : Edvard Grieg topside completed on time". Kvaerner. available at: https://www.kvaerner.com/toolsmenu/Media/Press-releases/2015/Kvarner-ASA-Edvard-Grieg-topside-completed-on-time/ (accessed 26.05 2017).

Kvaerner. (2015b), "Kværner ASA: Kvaerner-KBR JV wins Johan Sverdrup platform contract". Kvaerner. available at: https://www.kvaerner.com/toolsmenu/Media/Press-releases/2015/Kvarner-ASA-Kvaerner-KBR-JV-wins-Johan-Sverdrup-platform-contract-/ (accessed 26.05 2017).

Kvale, S. B., Svend (2009), *Det kvalitative forskningsintervju [The qualitative research interview],* Oslo, Gyldendal Akademisk.

Lin, Y.-C. (2014), "Construction 3D BIM-based knowledge management system: a case study", *Journal of Civil Engineering and Management,* 20**,** 186-200.

Lindner, F. and Wald, A. (2011), "Success factors of knowledge management in temporary organizations", *International Journal of project management,* 29**,** 877-888.

Matthews, J., Love, P. E., Heinemann, S., Chandler, R., Rumsey, C. and Olatunj, O. (2015), "Real time progress management: Re-engineering processes for cloud-based BIM in construction", *Automation in Construction,* 58**,** 38-47.

Nepal, M. P. and Staub-French, S. (2016), "Supporting knowledge-intensive construction management tasks in BIM", *Journal of Information Technology in Construction (ITcon),* 21**,** 13-38.

Newell, S. (2015), "Managing knowledge and managing knowledge work: what we know and what the future holds", *Journal of Information Technology,* 30**,** 1-17.

Oracle. (2016), "Oracle Primavera". available at: https://www.oracle.com/applications/primavera/products/project-management.html (accessed 16.11 2016).

PMI (2013), *A Guide to the Project Management Body of Knowledge (PMBOK Guide), Fifth Edition*, Project Management Institute.

Ramaji, I. J. and Memari, A. M. (2016), "Product architecture model for multistory modular buildings", *Journal of Construction Engineering and Management,* 142**,** 04016047.

RIBA (2013), "RIBA Plan of Work 2013 Overview". available at: https://www.ribaplanofwork.com/About/Concept.aspx (accessed 17.12.2017).

Sacks, R., Koskela, L., Dave, B. A. and Owen, R. (2010a), "Interaction of lean and building information modeling in construction", *Journal of Construction Engineering and Management,* 136**,** 968-980.

Sacks, R., Radosavljevic, M. and Barak, R. (2010b), "Requirements for building information modeling based lean production management systems for construction", *Automation in Construction,* 19**,** 641-655.

Sacks, R., Treckmann, M. and Rozenfeld, O. (2009), "Visualization of work flow to support lean construction", *Journal of Construction Engineering and Management,* 135**,** 1307-1315.

Schade, J., Olofsson, T. and Schreyer, M. (2011), "Decision-making in a model-based design process", *Construction management and Economics,* 29**,** 371-382.

Solibri. (2016), "Solibri Model Checker". available at: http://www.solibri.com/products/solibri-model-checker/ (accessed 13.01 2016).

Solihin, W. and Eastman, C. (2015), "Classification of rules for automated BIM rule checking development", *Automation in construction,* 53**,** 69-82.

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

Wang, W.-C., Weng, S.-W., Wang, S.-H. and Chen, C.-Y. (2014), "Integrating building information models with construction process simulations for project scheduling support", *Automation in Construction,* 37**,** 68-80.

Yang, J.-B., Yu, W.-D., Tseng, J. C., Chang, C.-S., Chang, P.-L. and Wu, J.-W. (2013), "Benefit analysis of knowledge management system for engineering consulting firms", *Journal of Management in Engineering,* 30**,** 05014005.

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