4D BIM implementation to improve EPC project performance from contractor’s perspective. A case study

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Abstract. The most significant benefits of 4D BIM are better visualization of construction work, better communication between project teams and improving project time and cost performance. 4D BIM allows stakeholders to visualize construction activities during project duration and identify potential spatial conflicts and schedule conflicts. Although researches related to 4D BIM has proven the benefits of 4D modeling in construction projects, these benefits are still questionable for EPC projects, whether it can compensate the initial costs and efforts to create the model. The implementation strategies across EPC project lifecycle also become fundamental issue. Through literature studies and structured interviews, this research identifies resource requirements, implementation strategies and the benefits of 4D BIM in improving EPC project performance.

1. Introduction

EPC projects in mining and oil & gas sector face major challenges in completing projects on time and on budget, as many as 98% of EPC mega projects experience 30% over budget and 77% of projects experience schedule delay of at least 40%. Despite that, manufacturing sector is experiencing faster growth in productivity due implementation of new technologies, the rate of improvement of productivity in EPC Projects remain the same in the last decades [1].

In terms of performance and progress control, managers traditionally base their decisions on S-Curves, Gantt Charts, Cost Reports and other visual aids to determine if the performance of a project is satisfactory or not, and based on this, make the necessary adjustments. However, traditional construction planning and control tools such as Gantt Charts, S-Curves and Time Location Charts do not provide a clear visualization of information, since the sequence of activities is not linked to the physical objects represented by those activities. Project progress is difficult to be tracked and visualized in Gantt chart method, whereas the works are done simultaneously in large-scale projects [2].

In S curve method, the cumulative amount of activity can be shown based on the costs incurred, the number of Man Hour spent and the amount of material used by the project, however this only shows the progress of the project over time and the deviation from plan progress in numerical value [3]. Furthermore, the form of the report does not provide information about specific activities that need to be completed next, interface information, spatial boundaries and critical activity information does not show visual references of deviations or delays that occur [4]. In brief the problems that arise are visualization and limited communication between the project planner and the execution manager in the field.
Building Information Modeling (BIM) technology has been developed by adding a time dimension known as 4D BIM which can be one of the solutions to visualize the progress of construction work into three-dimensional images. The benefits of using 4D BIM as a project planning method include increasing accuracy and enabling more detailed scheduling, construction work sequences can be better simulated, improve safety performance and better communication among project stakeholders [5]. Although researches related to 4D BIM has proven the benefits of 4D modeling in construction projects, these benefits are still questionable whether it can compensate the initial costs and efforts to create the model.

This research aims to identify the 4D BIM implementation strategies to optimize the benefits, identify resources requirements and analyze the impact of 4D BIM use in improving EPC project performance. A case study carried on a Power Plant 25 MW EPC project in North Sumatra, Indonesia from EPC contractor’s perspective.

2. Literature review

2.1. 4D BIM definition

The 4D BIM model can be defined as three dimensional (3D) combined with time (schedule) information-makes it easier for the project team to visualize the sequential construction process such that the appropriateness of construction plan can be thoroughly reviewed. 4D model is created by linking construction schedule to 3D model. This process of linking a schedule to a 3D model occurs in a 4D simulating program [6] Many specialized software appear to produce 4D models by connecting 3D models and schedules from separate platforms. Typically, this software requires 3D data models imported from CAD or BIM applications and Schedule data imported from planning/scheduling applications such as MS Project and Primavera. The scheduler then connects the components of the 3D model to the construction activities of the schedule and forms a 4D model based on time.

2.2. LOD and implementation strategies

The Level of Development is breakdown of the proportions of what is included in the model element. The level at which the component specifications, geometry, and information attached have been thought to what extent project team members can depend on information when using the model. In essence, Level of Development is to specify the information that the model must contain according to its use at the different stages of a project lifecycle.

The American Institute of Architects (AIA) defines five levels of developments: LOD 100 to LOD 500. At LOD 100, which is the pre-design stage, the model consists of 2D symbols to indicate the presence of elements. In LOD 200, elements are partially defined by describing estimates of quantity, size, shape, and location. With LOD 300, elements are defined with their exact dimensions and relative position to support precision. LOD 350 explains information about an element precisely and outlines the relationship and connection of elements with other components. The LOD 400 level outlines basic information about building various elements. With the LOD 500, the model begins to represent the functions of real life elements in buildings. It was shown that it is required to manage multiple graphical LOD corresponding to the different usages of the model either expected or unexpected. The graphical LOD necessary for construction phase is higher than the graphical LOD at pre-construction phase [7]. This research has study at which LOD, 4D BIM implementation shall be implemented across EPC project lifecycle.

2.3. Project key performance indicators

To measure a project's performance and to apply a benchmarking approach, it must first determine the Key Performance Indicators (KPIs) that are most important in determining the overall success of the project. A KPI is a compilation of data sizes used to assess the performance of construction operations [8].
Research conducted by David D. John (2018) [9] identified results and process-oriented Key Performance Indicators (KPI). The results-oriented KPI consists of cost, time, quality, safety and client satisfaction levels. Whereas KPI which is process oriented consists of communication management, resource management, cost management, effectiveness of schedule control, effectiveness of quality management, effectiveness of safety management, management and coordination of Human Resources. To achieve the objectives of this study two principal methodologies have been considered: 1. an extensive literature review on the performance measurement to identify the initial set of KPIs. 2. Exploration of the practitioner view to formulate the KPI measures from a 4D BIM implementation view point. The analysis of semi-structured interviews resulted in the development of following 4D based KPIs as represented in table 1.

Table 1. 4D based Key Performance Indicators.

| Factor | Performance Indicator | Attributes |
|--------|-----------------------|------------|
| KPI (Result oriented) | Financial | 1. Gross Profit |
| | | 2. Total CO Approved |
| | | 3. Actual Billing vs. Plan |
| Schedule Goal | 1. Schedule Performance Index (SPI) |
| | 2. Key Milestone Achieved |
| Cost Goal | 1. Cost Performance Index (CPI) |
| Quality Goal | 1. Document Review Cycles |
| | 2. Number of Non-Conformances |
| Safety Goal | 1. Fatalities |
| | 2. Total Recordable Injury Rate (TRIR) |
| Customer Satisfaction | 1. Customer Satisfaction Survey |
| Productivity Performance | 1. Engineering Man Hours Productivity |
| | 2. Equipment Utilization Index |
| | 3. Overall Construction Productivity |
| KPI (Process oriented) | Communication Management | 1. Communication Frequency |
| | | 2. Communication Effectiveness |
| | | 3. Communication Method |
| Resources Management | 1. Material management |
| | 2. Labor management |
| | 3. Subcontractor management |
| Schedule Management | 1. Schedule control |
| | 2. Planning efficiency |
| | 3. Smooth work process |
| Quality Management | 1. Effective quality management |
| | 2. Earlier detection of problems |
| | 3. Design efficiency |
| | 4. Rework efficiency |
| Safety Management | 1. Effective Safety Management |
| Productivity Performance | 1. Man Hours spent to complete construction |

3. Methodology

A Power Plant 25 MW EPC Project is used for the case study which was located in North Sumatra, Indonesia. 4D BIM model has been developed at the engineering (pre-construction phase) using Autodesk Navisworks Manage 2016 as project review software that supports intelligent 3D model-based design with scheduling, visualization, and collaboration tools. Primavera P6 Professional R8.1 is used for scheduling the project plan and imported into Autodesk Navisworks Manage software. The resources
Man Hour to develop 4D BIM model at pre-construction phase was defined based on project data records; meanwhile the resources Man Hour for construction phase was defined based on contractor’s database and expert estimation.

In the following parts, the author characterizes the Level of Development of 4D BIM across phases of a project, and on the basis of the above mentioned LOD definitions. The next aim is to analyses the benefits of 4D BIM technology to improve EPC project Key Performance Indicator based on survey result, qualitative feedbacks and structured interviews with EPC contractor practitioner.

4. Findings and Discussions

4.1. Resource requirements

Autodesk Navisworks Manage 2016 and Primavera P6 Professional R8.1 are required for 4D BIM implementation as explained above. Additionally 3D survey also required at the beginning of engineering phase to included project site condition into 3D model.

In this study the additional Man–hours was spent for 4D BIM implementation in Power Plant 25 MW Project having the following elements such as pile, foundation, steel structure, mechanical equipment, gas engine equipment, pipes, electrical and instrumentation. The hours were broken into the following phases:

1. Personnel software study (initiation phase), two months durations
2. 4D BIM - EPC schedule development (pre-construction phase), four months duration
3. 4D BIM - EPC schedule monitoring and controlling (construction phase), eleven months duration

Man Hour was calculated for additional activities to implement 4D BIM at initiation phase, pre-construction phase and construction phase as represented in table 2. About 19 project members were involved and additional 3,392 Man Hours were required for 4D BIM implementation across 21 months project lifecycle. In percentage, the total of additional Man Hour required was 1.11% of total project indirect Man Hours.
| No | Project Phase                                      | Additional Activities                                                                 | Number of Manpower Involved | Total Man Hours |
|----|---------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------|-----------------|
| 1  | Study & learning of software (initiation phase)   | 1. Personnel Study                                                                     | 19                          | 456             |
| 2  | 4D BIM development (pre-construction phase)       | 1. Conduct survey and field investigation - 3D Survey and photogrammetry                | 6                           | 24              |
|    |                                                   | 2. Modelling the structure of the project site into BIM                                 | 4                           | 40              |
|    |                                                   | 3. Determine the LOD (level of Detail) that will be used in integrating the Schedule and 3D models | 4                           | 40              |
|    |                                                   | 4. Analyzes additional project activities needed based on project conditions            | 2                           | 64              |
|    |                                                   | 5. Sequence of project activities simulation into a 4D BIM                               | 2                           | 20              |
|    |                                                   | 6. Construction activities schedule integration into 3D model elements                   | 15                          | 48              |
|    |                                                   | 7. Validation of Schedules and 3D models integration results by all disciplines         | 4                           | 124             |
|    |                                                   | 8. 3D model optimization and design based on simulation and integration results          | 3                           | 64              |
|    |                                                   | 9. Schedule optimization based on simulation and integration results                     | 19                          | 40              |
|    | **Subtotal**                                      |                                                                                       |                             | **464**         |
| 3  | 4D BIM schedule monitoring and controlling (construction phase) | 1. Input actual weekly construction progress into 4DBIM                                  | 2                           | 260             |
|    |                                                   | 2. Analyse project activities based on actual conditions at construction site          | 9                           | 636             |
|    |                                                   | 3. Analyze the remaining work in the field with the team with 4D BIM media             | 9                           | 558             |
|    |                                                   | 4. Present work plans for the next two and six weeks to the project team with 4D BIM media | 8                           | 146             |
|    |                                                   | 5. To coordinate the process of checking on schedule conflicts, space-time conflicts, design conflicts, design conflicts in the field, and conflicts between stakeholders | 9                           | 162             |
|    |                                                   | 6. To coordinate the process of checking the layout of the field for construction activities virtually to analyze the access road, the need for heavy construction equipment space and the area to place temporary material | 9                           | 162             |
|    |                                                   | 7. To coordinate the process of checking to avoid conflicts with Construction activities | 11                          | 266             |
|    |                                                   | 8. Shows delay activities virtually using 4D BIM media                                   | 9                           | 162             |
|    |                                                   | 9. Shows construction performance virtually using 4D BIM media                          | 9                           | 162             |
|    |                                                   | 10. Shows project critical path activities virtually using 4D BIM media                 | 9                           | 162             |
|    |                                                   | 11. Schedule re-baseline based on the results of 4D BIM evaluation and analysis         | 3                           | 56              |
|    | **Subtotal**                                      |                                                                                       |                             | **2,472**       |
|    | **Total**                                         |                                                                                       |                             | **3,392**       |
4.2. Implementation strategies

In the initiation phase case study, 4D BIM implementation started since contract award and the first step is to define Work Breakdown Structure and discuss with engineering team who is responsible to develop 3D model. This step is very important to prevent major adjustment in engineering (pre-construction) phase. The schedule breakdown structure shall be in line with 3D level of development, for example LOD 300 represents project master schedule level 3. The other important activity is to study and learn 4D BIM supporting software by all project members involved in 4D BIM implementation.

In the pre-construction phase, it is recommended to link 3D model with project master schedule when 3D model has achieved LOD 300, thus in line with project master schedule level 3. In the case study project LOD 300 also defined as 30% 3D model progress and design review meeting was conducted between all project stakeholders at the end of month# 2. LOD 100 and LOD 200 are not recommended to start 4D BIM implementation due to the maturity of 3D model is not sufficient and the 4DBIM benefits will not optimal.

In the construction phase, the 4D BIM implementation was started at the end of month# 6 or when 3D model has achieved LOD 500 or also defined as 60% 3D model progress. This arrangement is consistent with rolling wave planning scheduling method. In the construction phase it is important to implement 4D BIM up to daily activity schedule or schedule level 5. LOD for 4D BIM implementation across EPC project lifecycle is shown in figure 2.

4.3. The impact of 4D BIM implementation to improve key performance indicators

Interviewees were asked to rank the impact of 4D BIM implementation to improve identified KPIs. The ranking of the impact was done by using a five (5) point Likert Scale (where 1= has no impact, 2 = has very low impact, 3 = has fairly impact, 4 = has impact, and 5 = has high impact). The impact will be further classified in qualitative terms (rating on a scale).

Figure 3 and figure 4 represents the weighted (%) ranking of the KPI on the basis of the views of the respondents. As shown in figure 3, the implementation of 4D BIM has the highest impact to improve project productivity (83%) for result oriented KPI and the highest impact to improve schedule management (97%) for process oriented KPI as shown in figure 4.
5. Conclusions
This paper reported a 4D BIM implementation case study on Power Plant 25 MW Project in North Sumatra, Indonesia. The first part of the research defined resources requirements for 3D BIM implementation across project lifecycle. About 19 project members were involved and 3,392 Man Hours were utilized for initiation phase, develop 4D BIM with LOD 300, develop 4D BIM with LOD 500 and to implement 4D BIM as construction activity controlling and monitoring tools. 4D BIM implementation was started since project award for initiation phase.

In the pre-construction phase, 4D BIM was developed by connected 3D model LOD 300 with project master schedule level 3. Furthermore, in the construction phase, 4D BIM was implemented to control and monitor construction activity by connected 3D model LOD 500 with project schedule level 5 which shows construction daily activities.

It is shown 4D BIM implementation has potential benefits to improve project productivity and time performance. Moreover the benefit of 4D BIM implementation has higher impact to improve schedule and communication management process during construction phase.
References

[1] IHS Herold Global Project Database 19 November 2013
[2] Mubarak S 2015 Construction Project Scheduling and Control (New Jersey: Wiley)
[3] Nicholas J and Steyn H 2012 Project Management for Engineering, Business and Technology (Oxon: Routledge)
[4] Koo B and Fischer M 2000 Feasibility study of 4D CAD in commercial construction J. Constr. Eng. Manag. 126 4 p 251-60
[5] Swapnesh P R and Valunjkar S S 2017 Improve the productivity of building project using building information modelling (bim) based 4d simulation model IJRASET 5 p 45-98
[6] Pitake S A and Patil D S 2013 Visualization of construction progress by 4D modeling application IJETT 4 p 3000
[7] Boton C, Kubicki S and Halin G 2015 The challenge of level of development in 4D/BIM simulation across AEC project lifecyle. A case study. CCC 2015 123 p 59-67
[8] Elshakour A H A, Al-Sulaihi I A, Al-Gahtani K S 2012 Indicators for measuring performance of building construction companies in Kingdom of Saudi Arabia JKSUES 25 p 125–34
[9] John D D 2018 Building Information Modeling (BIM) Impact on Construction Performance (Georgia: Georgia Southern University)