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APPLICATION OF 4D BRIDGE INFORMATION MODEL AS A LEAN TOOL FOR BRIDGE INFRASTRUCTURE PROJECTS: A CASE STUDY

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ABSTRACT

Construction projects require the coordination of multiple organizations. The production flow of these projects is often hampered through sources of wastes such as improper utilization of the skills of the labours and lack of coordination with the multiple organizations involved in these projects. Bridge information modelling provides a powerful platform for visualizing work flow and collaboration between organizations throughout the life cycle of the project.

In this paper, 4D bridge information models for a concrete bridge (flyover) construction project was built through integrating 3D BrIM model with the schedule. The developed 4D bridge information model enabled value addition through improved visualization, co-ordination and communication among project participants. This study provides a practical contribution by showing that project stakeholders can use 4D BrIM models as a lean tool to prevent undesirable situations and reduce the overruns, rework and improve the effective utilisation of labours in Bridge construction projects.

KEYWORDS

Lean tool, bridge information modelling, visualisation, coordination, 4D BrIM model.

INTRODUCTION

Construction projects involve multiple participants where they execute independent and mutually exclusive goals, often resulting in poor coordination, rework, and incorrect work. Lack of coordination and communication were considered as one among the factors attributing to generation of construction wastes (Gill 2012). Lean concepts provides a way to minimize waste and maximises value of the system (Koskela 1993; Hosseini et al. 2011). Lean concepts considers 7 types of waste namely overproduction, inventory, extra-processing, motion, travel, defects and waiting in a process flow (Dubler et al. 2010). Though lean concepts were originally developed for manufacturing industry

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and the construction industry incurs high level of variability, lean principles of flow design were common for both manufacturing and construction processes (Koskela 1993). The reduction in wastes can be achieved through adoption of lean tools and techniques like Last Planner System (LPS), Concurrent engineering, work structuring, Value Stream Mapping(VSM), daily huddle meeting and many others. The implementation of lean methodologies in construction imparts significant improvements in workflow and overall performance of the process (Castillo et al. 2015) and improves coordination and communication among project teams in construction (Castillo et al., 2015; Mahalingam et al., 2015).

As like lean concepts, Building Information Modelling(BIM) also shares a common platform of coordination and collaboration throughout the projects lifecycle (Porwal and Hewage 2013). Unpredictability in the construction were being the source of waste and disrupts the performance of the process (Yu et al. 2009). The adoption of BIM helps to visualise the process, coordinate and communicate information's for the better performance of the project. (Chen and Luo, 2014; Mahalingam et al., 2015).

Though BIM and lean construction differs, research states they share significant synergies and efforts were taken in literatures to integrate lean and BIM in construction process (Dave et al. 2010). This paper adopts 4D BrIM models to improve coordination and communication among project participants in an ongoing bridge construction project in India. This paper tries to minimise the lean wastes associated in the construction process of the bridge construction project through the application of 4D Bridge information models(BrIM). The BrIM models were used to improve the coordination and reduce the uncertainties in the workflow.

LITERATURE REVIEW

REVIEW ON THE APPLICATIONS OF BIM

Building information modelling (BIM) is generally referred as both technology as well as a process (Mahalingam et al. 2015). BIM has changed the traditional way of work with respect to design and execution in architecture, engineering and construction (AEC) industry (Cheng et al. 2016). Currently around 122 BIM software systems are present and are being used in different domains of construction industry namely the architecture, structural engineering, building services, project management/design coordination, facilities management, sustainability and geographical information systems-BIM (Kumar and Mukherjee 2009). The use of BIM has been practiced in various stages of construction and different purposes like visualisation, estimation, coordination, monitoring and control, asset management, rehabilitation and risk mitigation.

Given the success and benefits of adoption in BIM in AEC of building projects, BIM has also been adopted for infrastructure projects like bridges and tunnels and was referred to as Civil Information Modelling(CIM) (Cheng et al. 2016). The studies suggest, the adoption of BIM in infrastructure generates value creation, enhance coordination and communication through common data exchange platforms (Kumar et al. 2017).

Application of BIM in bridges, also called as Bridge Information Modelling(BrIM) (Marzouk and Hisham 2014) were studied by various researchers. Augmenting object and its parameter as openBriM standards to facilitate interoperability on information were studied (Jeong et al. 2017). These OpenBrIM neutral schema were mainly applied to perform engineering analysis of bridge structures (Jeong et al. 2017; Xiao; et al. 2017). As like the uses of BIM in building projects, the BIM on bridge structures offers various applications like 3D modelling, Visualisation, clash detection, structural analysis, Quantity Estimation, Project monitoring and control, Risk Assessment, Assets maintenance (Kim et al. 2011; Marzouk and Hisham 2014; Fanning et al. 2014; Zou et al. 2016; McGuire et al. 2016; Xiao; et al. 2017). The use of BIM on bridge infrastructure were proposed in different stages in construction like preconstruction, post-construction, construction.

However only limited studies like visualisation, setting out of site boundaries (Chong et al. 2016), cost control (Fanning et al. 2014), earned value analysis (Marzouk and Hisham 2014) and schedule management via telepresence (Kang et al. 2016) were presented during construction stages, while other applications were proposed on preconstruction stages.

REVIEW ON THE INTEGRATION OF LEAN AND BIM

Though there exist differences in processes between BIM and lean, they both share some set of concepts in common. Studies have indicated the synergies existing between through matric interactions and have identified the existence of 56 constructive interactions between lean and BIM (Sacks et al. 2010). Khanzode (2010) addressed the interaction of VDC (Virtual Design and Construction) and lean in the name of IVL (Integrated, Virtual Design and Construction and Lean) to develop a pull schedule and improve the coordination of MEP systems in a project. In a study, Zhang and Chen (2016), considers BIM as one among the lean tools and techniques to eliminate wastes in the system. Further studies have proposed the use of BIM and Lean concepts in case studies to find how BIM facilitate the adoption of lean in construction and concludes by sighting the benefits of increased value and waste reduction by them (Gerber et al. 2010). In contrast, studies were also made to investigate the mediation of lean practices for BIM adoption and argues lean enabled effective BIM adoption (Mahalingam et al. 2015). Interaction of BIM and lean were discussed to develop an integrated BIM simulation framework to produce reliable plan and minimise waste in the construction process (Jeong et al. 2016).

The collaboration of lean and BIM concepts were proposed as solutions for improvement and overcoming the problems in design management practices (Tauriainen et al. 2016). Several recommendations like target value design, big room were made to improve the flow of information and communication among participants. In another study the concepts of information technology and lean were combined in the form of simulation game called RBL(RFID/BIM/Lean) and were developed as a learning tool for production of prefabrication housing, where metrics of PPC, productivity index were used to evaluate the simulation (Li et al. 2018). The study of lean and BIM was also applied for the operation and maintenance processes to enhance integration and sharing of information and reduce waste via pull planning (Shou et al. 2014). Likewise, the use of BIM and lean is also incorporated in infrastructure projects. Lean and BIM concepts of LPS and visualisation respectively were mainly integrated to develop a software named VisiLean to control projects (Dave et al. 2010). Though Dave et al. (2010) proposed a way to apply lean and BIM for infrastructure projects, the idea of application in infrastructure projects to control project performance remain unexplored.

RESEARCH METHODOLOGY

A constructive research methodology is adopted in this paper. The Constructive research as a methodology provides strong grounding in identifying a practical problem from practice, complemented by related literature and the identified research problems are solved by developing or constructing a solution which will be operationalised to determine its workability and appropriateness (Oyegoke 2011). This kind of research pertains to creating and testing an artefact. Case studies allows investigators to understand and analyse the holistic and meaningful characteristics of contemporary events (Yin 1994). This paper considers an ongoing bridge project as a case for study, identifies associated problems and develops 4D bridge information models to minimise the problems faced during construction.

The study considers direct interviews, site drawings and site documents as the source of evidences for data collection. The study captures contemporary events of the case considered and performs modelling activities. The research methodology adopted to perform the study is shown in figure 1.

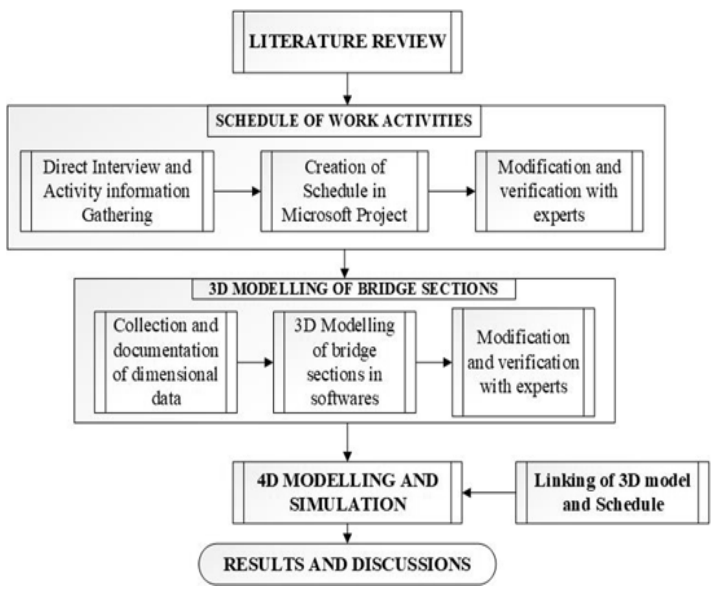

Figure 1 Research Methodology

BACKGROUND OF CASE STUDY

The paper considers an ongoing bridge construction as a case study for the application of lean and BIM concepts. The bridge spans to a total length of 711 metres with two approach roads, 10 piers and 9 spans each of 30m length. The width of the bridge is designed to support 6 lane provision. The duration of completion was estimated to be 2 years and is currently ongoing. The project considers traditional method of project management and do not use lean and BIM concepts in design and execution stages. The details of the project are tabulated in table 1.

Table 1: Details of Case study

Content	**Description**
Project Title	Construction of flyover at the junction of NH-45 and Vandalur
Location	Vandalur, Chennai
Estimated budget	55crores
Estimated duration	2 years
Purpose	To reduce traffic congestion at Vandalur junction

DEVELOPMENT OF SCHEDULE

A schedule representing the entire sequence of activities from the planned start date were developed. The project site uses a schedule in an excel format, however they were not shared due to confidentiality issues. Hence a new baseline schedule as per the sequence of construction in site was developed in Microsoft Project 2016. From direct interview with the project manager at site, details of construction activities like duration of activities, start date, resource required and sequence of activities were collected and a working schedule was prepared. The developed schedule was reviewed by the project manager and necessary modifications were incorporated. The developed schedule was then used for tracking the performance of the project. The baseline was set and the tracking of progress was performed. The S curve profile for the planned and actual progress were determined using the software. This enabled the project team members to find out exact delay incurred and other performance matrices. The developed s-curve is shown in figure 2.

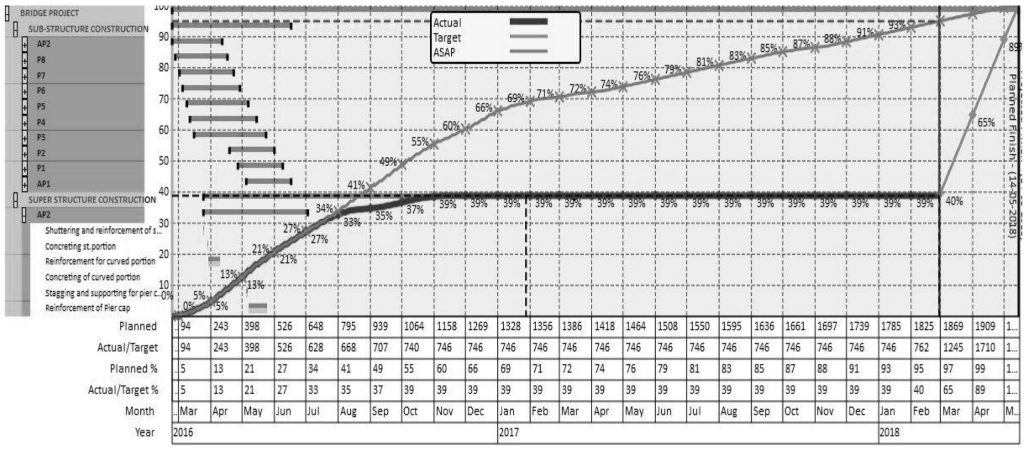

Figure 2 Developed S-Curve

DEVELOPMENT OF 3D MODELS

Though use of 3D BIM models were used in AEC industry, still 2D drawings were used for design and construction for bridge infrastructure projects (Lee et al. 2012). The case project used only 2D drawings for design and construction. The printed 2D drawings of the bridge was studied carefully and were used to design the elements in modelling software Autodesk Revit 2018. Use of geometric and parametric 3D models of bridge elements were adopted in the study. The structural elements like column, footing, beam, slabs were modelled as 3D Revit family members. The parametric model of footing family of bridge and the geometric model of longitudinal girder families are shown in figure 3.

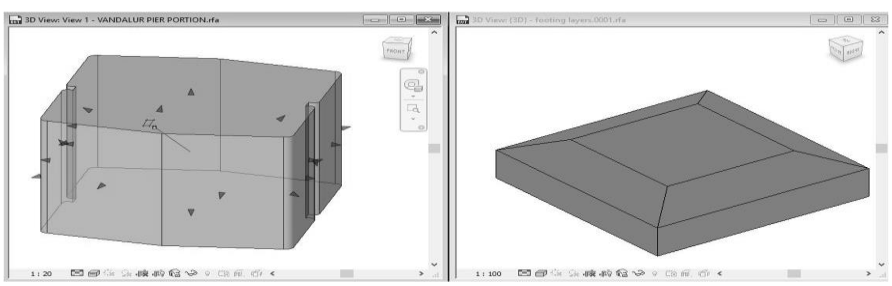

Figure 3 Representation of developed Revit family members

Use of opinions from the expert in the field of modelling were considered for developing the models. The bridge information like material of the section, strength of concrete and other properties were given as input in the 3D models. The necessary modifications in the models were made as per the review and discussions with the project manager at site. The developed 3D model is shown in figure 4 below.

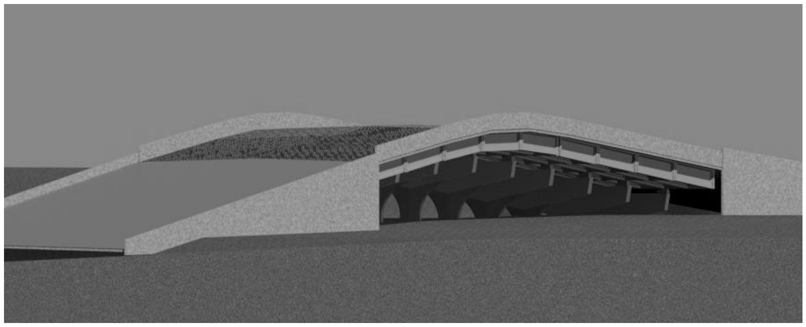

Figure 4 3D Rendered Image of the bridge

From the developed 3D models, the estimation of quantities of materials was performed. This enables the participants to estimate the work activities in short duration of time. The project members were then trained to use a collaborated platform where they can visualise, estimate quantity and perform analysis. The sample estimate of pier cap portion is shown in figure 5.

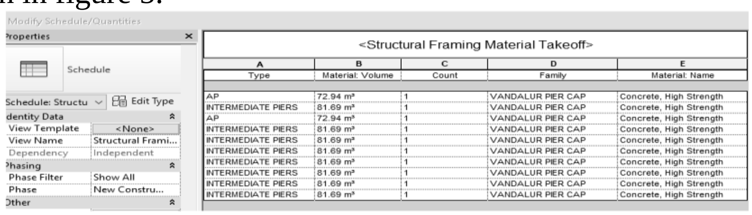

Figure 5 Quantity take-off from 3D models in Revit

DEVELOPMENT OF 4D MODELS

The schedule and the 3D model were then linked together to develop a 4D model in Naviswork (figure 6). The 4D simulation was presented to the project participants in their weekly meeting. Along with the simulation of entire construction process, comparison of planned progress and actual process through simulation was also performed. This helps the participants to have a clear virtual real time idea of how far they were lagging and what they have to accomplish in future periods.

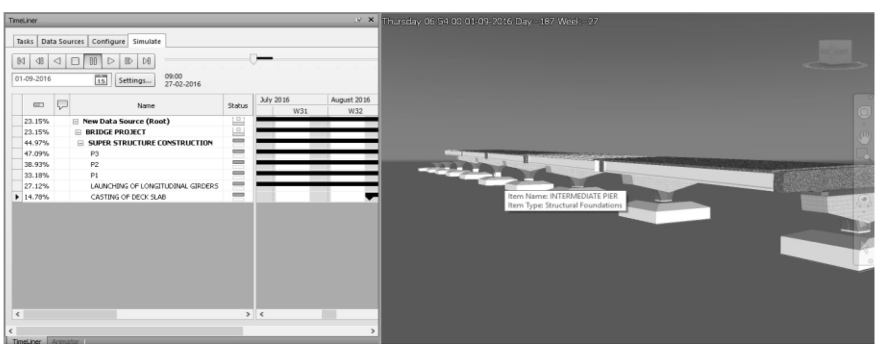

Figure 6 4D simulation of the bridge

From the obtained S-Curve, the actual completion status of the project was found to be 50%, while the planned completion status has to be 94%. The major factor contributing to the delay and non-achievement of planned targets is poor coordination between the contractors and sub-contractors. This results in underutilisation of the efficiency of the labours in site. The BrIM models were then presented to the project team and they have been explained to the project team by the authors. It further created a space to share individual's ideas and opinions about the progress of work and the problems faced. The visualisation of 4D simulation of activities enabled the participants to visualise virtually the problems during construction and to suggest an effective way to implement the activities to complete it within the planned target dates. This enabled collaboration and coordination among different crews present in the process. As a result, the project team was able to understand their lacking potential and places where they can improve their potential with the available resources in hand. It helps to effectively use the potential skills of the labours thereby reducing the waste of underutilisation of the skills of the participants in the project. It was clearly observed that the project team was interested to work on these platforms through their conversations and discussions. The participants at the meeting were enthusiastic to further discuss about the development of models. Thus 4d Brim Models were used as a lean tool to reduce rework and overruns in the project. The sequence of construction simulation is shown in figure7.

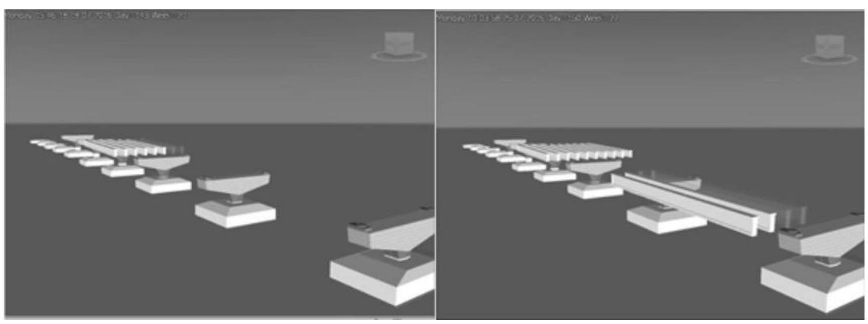

Figure 7 Simulation of construction sequence

LIMITATIONS OF THE STUDY

Though the study applies BrIM as a lean tool in a bridge infrastructure project to reduce rework and overruns, the paper fails to identify the combined effect of lean and BIM in the study.

CONCLUSION

Study of the application of 4D BrIM models are limited in literature. This study develops simulation 4D BrIM models for an ongoing bridge construction project to enable visualisation of entire construction process. The simulation of planned performance and actual performance were performed. The project team used these models for their discussion to make effective decision to improve their further performance. The models and simulation enabled collaboration and coordination among the different labour crews in the construction process. Thus the study concludes that application of BrIM as a lean tool enables value addition through improved visualization, co-ordination and communication among project participants. However, further studies are needed to explore hidden opportunities underlying the application of lean and BrIM in infrastructure projects.

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