Mchugh K., Dave., B and Craig, R. (2019). "Integrated Lean and BIM Processes for Modularized Construction – A Case Study" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.),* Dublin, Ireland, pp. 227-238. DOI: https://doi.org/10.24928/2019/0252. Available at: <www.iglc.net>.

INTEGRATED LEAN AND BIM PROCESSES FOR MODULARISED CONSTRUCTION – A CASE STUDY

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ABSTRACT

Integrated lean and BIM practices have a proven track record of improving the efficiency of the construction project lifecycle as demonstrated by several case studies and research projects. Lean and BIM synergies range from design coordination to pre-construction, production management and eventually handover and operations. Similarly, offsite manufacturing and modularisation also has a proven track record of improving the effiencies of the production phase and there are significant synergies between lean and offsite. Although lean construction is increasingly being applied on construction projects, applications that support its implementation on construction site remain limited. Production is significantly managed through manual processes and disparate systems. Previous case studies have proven that the use of BIM with lean practices during the construction phase improves the efficiency of planning.

One of the major aspects of lean and BIM implementations is the support of the Last Planner System and tracking of production status to ensure production runs smoothly. While 4D planning has been used to support pre-construction planning and first run studies, it has had limited success with tracking real-time production status and supporting the Last Planner System.

This paper provides an insight into an integrated lean and BIM implementation project supporting a highly modular and offsite production process on a data centre project. The case study highlights how lean and BIM can help the team to visualise the production plans, control the production in the field, report accurate production status and support the continuous improvement process.

KEYWORDS

Lean construction, BIM, offsite manufacturing, digitisation, lean and BIM.

INTRODUCTION

Production management in construction is directly linked to successful completion of construction projects, and yet an area that remains relatively ad-hoc and dependent on manual processes (Zhang 2005). In terms of productivity, a meta-analysis of wasted time in construction by (Horman and Kenley 2005) reported that over the last 30 years, almost

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49.6% of time was wasted during construction in non-value adding activities. Similarly, a research carried out in Sweden showed that only 15-20 % of the workers time is spent in direct work (i.e. carrying out the planned activity) (Jongeling and Olofsson 2007). There are similar studies around the world, which have reported sub-optimal performance of construction projects in terms of productivity and efficiency (Ramaswamy and Kalidindi 2009; Teicholz et al. 2001). These observations can be directly linked to sub-optimal performance of the production management systems in construction.

A production management system can be defined as a set of tools and processes that are put together to tackle the construction process on a given project. It is a complex system that encompasses a wide range of sub-systems including (but not limited to) planning and scheduling, procurement, production control, design management, subcontract (or human resource) management and various other support systems such as safety, and quality management. All these sub systems have to be effectively managed in order for the production management to perform efficiently.

On a higher level, it can be said that production management tackles two main types of information flows, i.e. product flow and process flow (Sacks et al. 2010). The product flow deals with design related knowledge, i.e. what is to be built/constructed; whereas the process related flows deal with the process of construction itself, i.e. how, when, where and who of the construction process. Production management in construction is also information intensive in nature, where systems at various operational levels including office and site based organisations have to be in constant interaction with each other.

One of the biggest factors that causes waste on construction projects is variability. It has been long argued that offsite manufacturing can reduce variability and improve flow on construction projects. Offsite manufacturing or modular construction also improves aspects such as safety and quality as production happens in a controlled environment. From this perspective, offsite manufacturing helps achieve many lean principles.

This paper explores a hypothesis that integrated lean and BIM practices can support modular construction and help improve production efficiencies. The paper begins with an introduction to the subject area followed by a brief literature review on integrated lean and BIM practices. A case study is presented where an integrated lean and BIM system was implemented to support modular/off-site production on a data centre project in Dublin, Ireland. This is followed by discussion and conclusions.

LEAN BIM AND DIGITAL – A STATE OF THE ART REVIEW

Recently, an increasing number of researchers have discussed the potential synergies between Lean Construction and Building Information Modelling (BIM) (Oskouie et al. 2012; Sacks et al. 2010; Shou et al. 2014). Simultaneous implementation of BIM and lean in the field has also shown promise as exemplified by recent case studies (Eastman et al. 2011). While the lean construction concept addresses the problems inherent to the construction process, BIM overcomes the hurdles that the 2D Computer Aided Design (CAD) technology presents and offers solutions to efficiently handle the product model (of the construction project).

Some key aspects that emerge strongly support the notion that the synergy of Lean Construction and BIM spans the entire lifecycle of the project and not just design activities. In the original study on identifying lean and BIM synergy (Sacks et al. 2010) it was found that three lean principles had the most interactions with BIM functions (i.e. they are best supported by BIM): i) reduction of waste by getting the quality right first time (through a better designed product, reducing the product variability, i.e. changes during the later stages of design); ii) improving flow and reducing production uncertainty which eventually leads to; iii) reduction in overall construction time.

It can be deduced that simultaneous implementation of Lean and BIM can lead to a successful project delivery. Several initiatives in the past have addressed the synergistic potential of these two aspects in construction.

Current state of the art in Lean and BIM integration

In an effort to evaluate the impact of what was termed 'Computer Advanced Visualisation Tools' (CAVT), (Rischmoller et al. 2006) used a set of lean principles as the theoretical framework. Based on the case studies conducted over a four year period, it was concluded that application of CAVT results in waste reduction, improved flow and better customer value, indicating a strong synergy between the lean construction principles and CAVT. Here, the authors use the term CAVT in place of BIM.

In another attempt to integrate lean construction processes with BIM, (Khanzode et al. 2006) attempted to provide a conceptual framework to link Virtual Design & Construction (VDC) with the Lean Project Delivery Process (LPDS). The authors claim that the "VDC approach allows a practitioner to build a symbolic model of the product, organization and process (P-O-P) early before a large commitment of time or money has been made to the project". (Gilligan and Kunz 2007) reported that the use of VDC in an earlier project was considered to contribute directly to the implementation of lean construction methods

(Sacks and Barak 2008) discussed the potential contributions of BIM to visualisation of the product and process aspects of construction projects in terms of lean construction principles. They provided examples that illustrate the use of BIM and related technologies to enable a "pull flow" mechanism to reduce variability within the construction process. (Sacks et al. 2010) have developed a research framework and prototype called KanBIM. The main goal of KanBIM research is to propose, develop and test a BIM-enabled system to support production planning and day-to-day production control on construction sites.

(Dave et al. 2011; Dave 2013) proposed VisiLean that aimed to integrate the Last Planner workflow with BIM. VisiLean was developed to support the lean production management workflow on the job site and to support the production crew/site teams collaborate effectively (i.e. the Last Planners). From this perspective, the proposed system primarily addresses two major strands of the production system: i) production management process representation; ii) product representation and visualisation. Additionally, there are further requirements to support the i) communication between operatives and; ii) delivery of accurate reports to facilitate better decision-making.

While previous research and certain case studies proved the successful synergy between lean and BIM in construction, commercial software to support these interactions were not present until now. Also, majority of commercial software provided pointwise solutions, i.e.

either BIM, top-down project management or bottom-up sticky note type isolated planning software that prevented an integrated approach to production management with lean and BIM. Commercialisation of VisiLean concept aimed to bridge this particular gap within the construction management domain.

CASE STUDY

PROJECT BACKGROUND

Undertaken by Mace Ireland, Project CLN, is a commercial development consisting of three single-storey data centres, split into three phases, to be powered by a purpose built 220kV Substation (also part of the campus), on a 95 hectacre (Ha) greenfield site in Clonee, Co Meath, Ireland. The data centre buildings include roof top mechanical equipment and measure up to 8.6m to the roof eaves, with a parapet wall up to 9.1m and a roof mounted plant screen wall around roof mechanical equipment up to 15.9m. The site infrastructure includes access roads, car parking, internal roads, entrance security hut, landscaping and a 220kV substation.

The 3rd phase of the project required the construction of a third single storey data centre building containing 4 data halls with a gross floor area of 25,400m2 and a data capacity of 36MW and in addition, an ancillary administration and office building of 4,360m2 and associated parking.

MODULARISATION

Prior to the modularisation, the assembly process for the fitout of data halls featured a “stick built” method of assembling the support grid, which includes all of the high-level services. Later, the current state mapping highlights many challenges; Each component had to be assembled at height which brought with its obvious safety and programme risks. It’s also a very time-consuming process, tying up large work areas at any one time and preventing multiple contractors from being able to work concurrently. As such it forces linear working methods, where each activity is dependent on one another, elongating lead-times.

The team took a system thinking approach to the problem and looked holistically at the product, the process along with the management system. The Mace DfSMA (Design for Safety, Manufacturing and Assembly) approach was used in conjunction with Lean process analysis and improvement methods to identify a Modular solution along with a future state process.

The team designed and developed a pre-fabricated frame, which could be constructed at ground level to reduce the work at height. A purpose-built temporary factory facility was set up on site to accommodate the efficient assembly of the modules and minimise transportation time / distance into the data hall for fitting.

Considering the installed pre-fabricated frame with all the fitouts as a final production unit or “Module”, the entire production system required to be formulated for hundreds of modules up to microdetails considering logistics, production pace, resource availably, and process constrains.

Figure 1. Different trade contractors are discussing their upcoming activities, contains and issues in the weekly planning meeting.

Entire process involved different organisations with dedicated teams doing numbers of internal handovers. Slight delay in these handovers can pose a considerable impact to the production flow and subsequently the overall production as knock-on effects would impact the forward tasks. Additionally, the monitoring and tracking of microlevel production plan is burdensome yet crucial to be proactive in production control and management. On top of that, the necessity of having elaborated execution planning takes significant administrative work. The team made use of a highly sophisticated collaborative digital room for such coordination meeting as can be seen in Figure 1.

Managing and coordinating such production system requires significant efforts on a daily basis. In such instances, management team's major focus gets directed to the coordination and work administration rather than addressing the issues and providing better working environment for the execution. Therefore, an inevitable demand for highly-functional management system which can deal with the detail and dynamic complexities posed by mentioned production system was gradually increasing.

The team had been using the Last Planner System to better manage lookahead and weekly work plans and commitments using the traditional sticky notes approach. However, the lean champion felt the need to improve the process with an electronic last planner tool that would help with not just micro level planning but integrate it with the overall plan and the building information model in order to improve predictability and tracking. The team identified VisiLean as a potential system that would replace the traditional sticky notes with a systematic planning and execution system.

LEAN AND BIM IMPLEMENTATION

For the communication ease, entire data centre is divided into four zones namely Zone-A, Zone-B, Zone-C, Zone-D. Each zone has specific number of modules to be installed. Accordingly, the schedule was developed with respect to the zones.

During the phase planning, this zone level schedule was further elaborated by the project team to the module level. By using digital tickets, collaborative planning meetings were successfully Implemented keeping 3D model as a reference for interactive discussions rather than flowing through dozens of 2D drawings. Figure 2 illustrates the setup for collaborative meetings comprising 4D planning in cognizance with the relevant information.

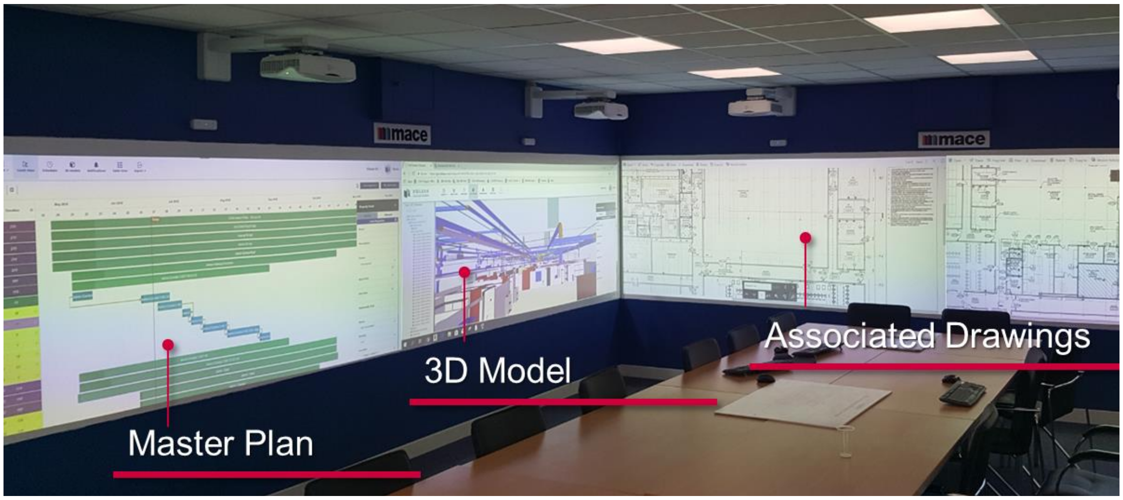

Figure 2. picture of digital display room setup, having plan and 3D model side by side along with the associated drawings

Now for detailing out the production process and the sequence, look ahead meetings were held where micro level planning was conducted. VisiLean dynamically linked lookahead planning and production control to the 3D model, transforming BIM into a visual planning tool enabling anyone to see at a glance the current build status. With the help of Visilean, the team tracked assigned responsibilities and the make-ready process. Lookahead planning was no longer confined to sticky notes and hidden in a room but integrated into a complete planning system where previously generated tickets can be used as a base for elaborated construction planning.

Here the challenge was to assign all the makeready details not only to the modules but also to the subprocesses in the module production. It takes a significant amount of efforts to carryout makeready process for each task in the micro-schedule. However, unlike using sticky notes, the project team was easily able to attach all the necessary details with the ticket itself. After the look ahead meeting each ticket (microlevel task) of the construction schedule would able to provide details like Makeready date, location, priority, important documents, qualities, plan constraints, notes etc. During the meeting, the tasks were assigned to the relevant organization member, who would then be able to provide status information using the mobile app. Figure 3 and Figure 4 show the lookahead planning along with allocation of tasks to workers using the VisiLean system.

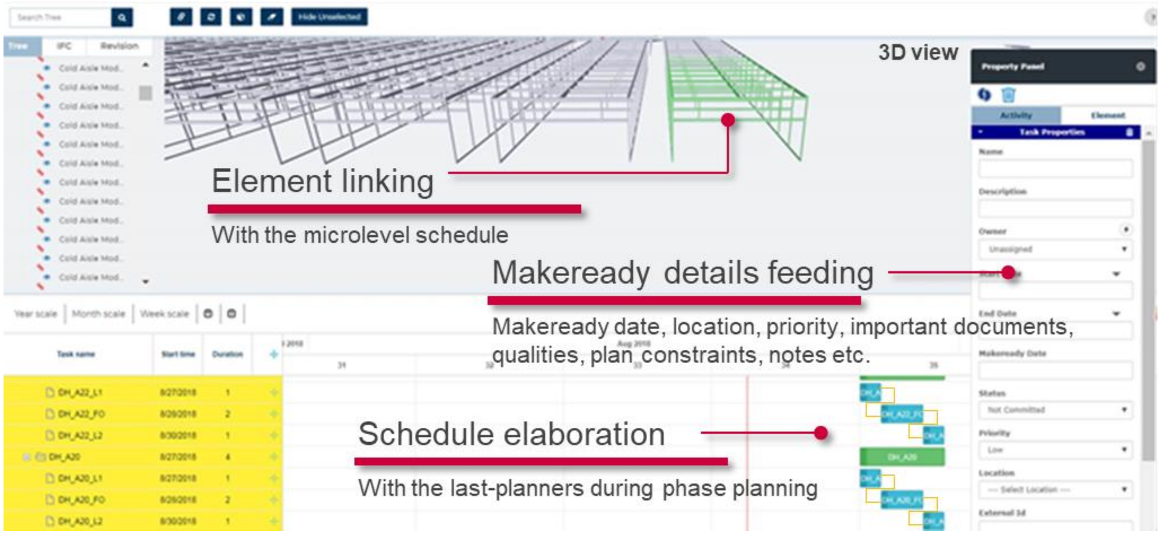

Figure 3 Creating elaborated schedules with makeready details in the Visilean.

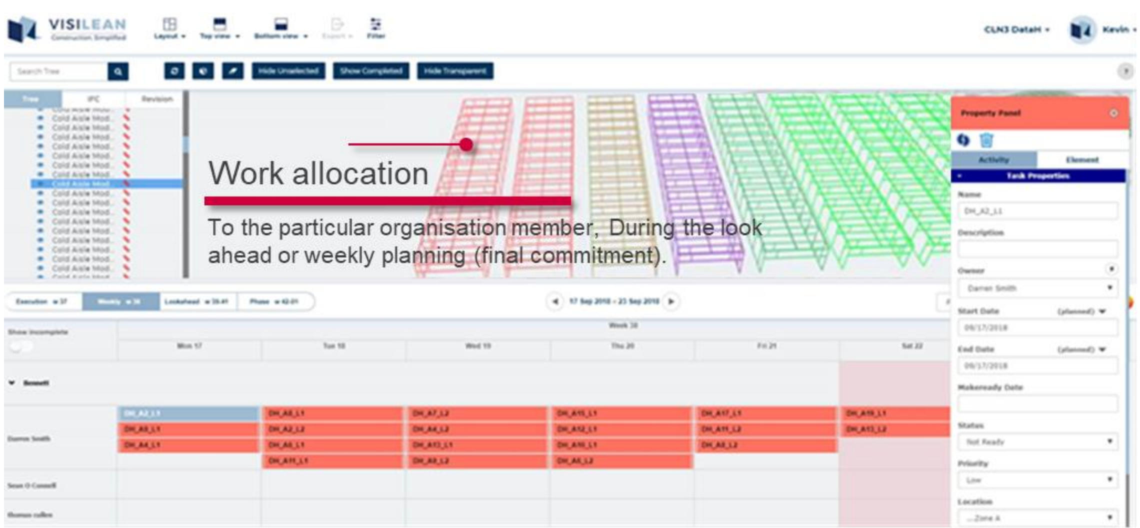

Figure 4 work allocation though commitments for the modules

Whilst conducting weekly planning, project team would primarily focus on the issues that has been raised during the make ready process. preliminary constrains or clashes for workspace, material, equipment, manpower, design were identified during this process. Later, the prominent issues are discussed and sorted out in the weekly meetings, and the final commitments for upcoming week scheduled were being made.

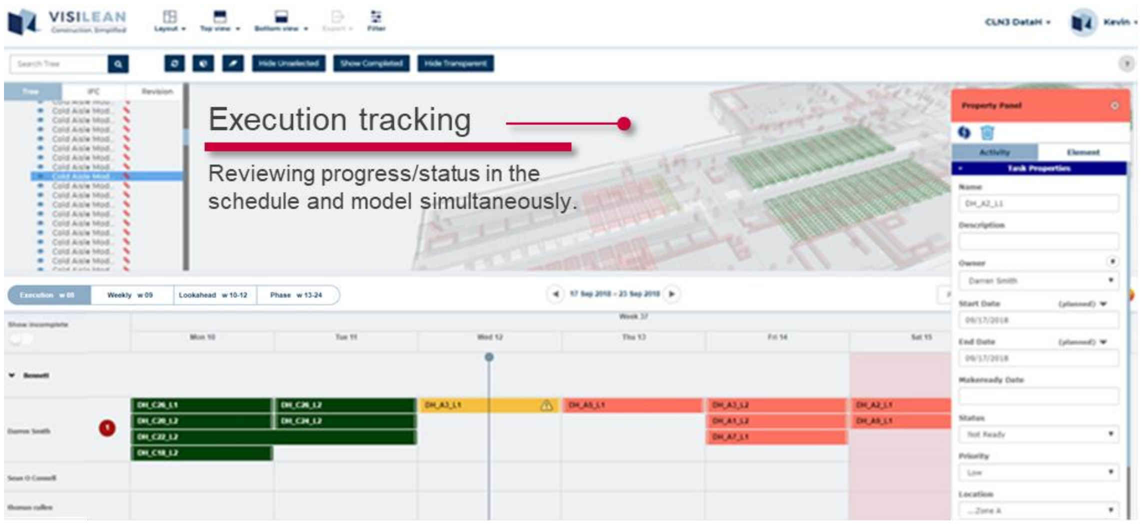

Figure 5 Visilean interface showing module progress tracking using colour coding in schedule as well as 3D model.

Asking for commitment for dynamic schedule was really challenging for the project team. Here, the Kanban style ticket approach to the execution was used to overcome this challenge, where the handovers to the different gangs has been achieved through push notification.

One of the critical issues earlier had been tracking progress and making reliable handovers within the team. In this context, the supervisors used Visilean mobile apps to update their work status directly using their smartphones/tablets which enabled smooth handovers as it prompted the subsequent task managers in real-time. Moreover, the task associated stopage or breakdown data was helpful in analyzing the planning efficiency and continuous improvement. As soon as a task finished, a notification to quality-supervisor was sent for checking the work. During execution, the system enabled supervisors to confirm task status in real-time out on site and triggered immediate notifications to follow on trades, enabling efficient and effective baton exchanges. Figure 6 shows the stoppage and warning tasks within VisiLean using "Andon" style colour coding for monitoring the work.

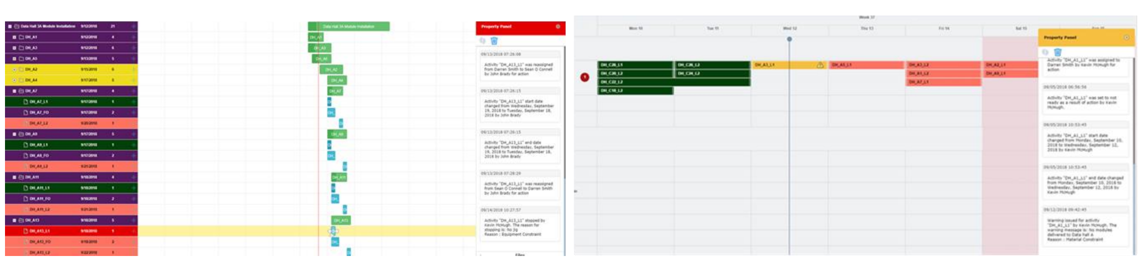

Figure 6 Issue/stoppage and warning alert in the Visilean.

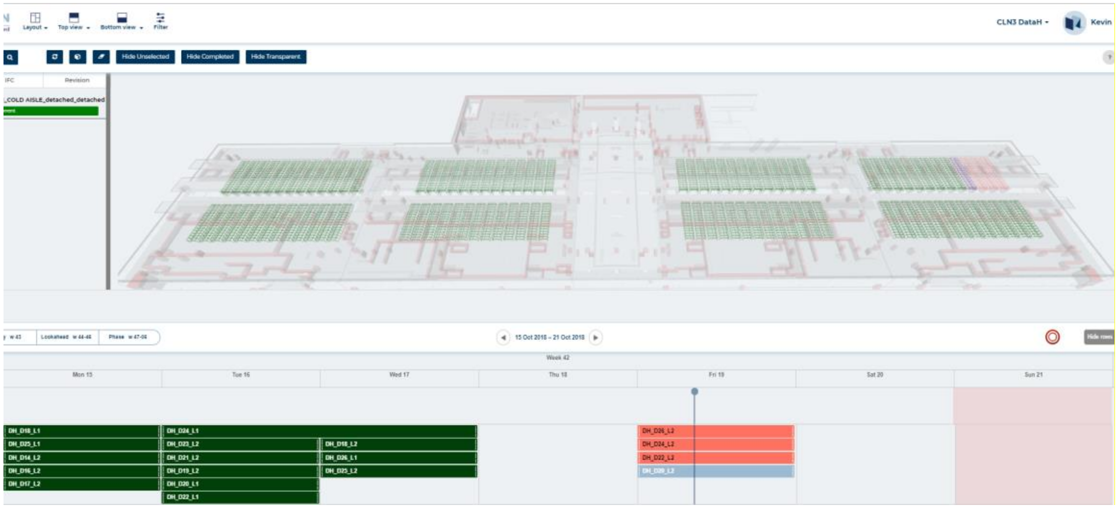

Figure 7 Integrated production plan with BIM in VisiLean.

The project team had a federated model available to them at LOD 450 level which could help them track work progress if it was connected with VisiLean. The VisiLean team helped integrate the BIM model with lookahead and weekly plan level. This enabled a unique "lean 4D" view within VisiLean that would visually show past, current and future plans with corresponding model elements in a colour coordinated fashion. Figure 7 shows the "lean 4D" view with the model on top and a weekly plan at the bottom to show the status of the current execution and work statuses. The bottom section shows the plan, with the top section dynamically linked to the model. With one glance the production and management teams can clearly see what modules are still to be completed and when this is planned to be done (indicated in red). In case of any problems, the management team could take proactive action to help streamline production.

DISCUSSION

While previous lean and BIM projects were achieved through manual intervention of internal and external consultants and integration of various different systems, scaling their implementation on larger more complex projects has been challenging. Sustainment of the integrated lean and BIM effort in this case was achieved through the adoption of the management systems deployed (VisiLean and Last Planner), coupled with a dedicated team and a collaborative culture supported by the Project Director. A regimented process that was developed in collaboration with supply chain members that ensured discipline in the planning, scheduling and control processes alongside digital solutions such as VisiLean made sure that on-field process clashes were avoided and learning was improved.

The management of trade handovers was improved using 4D tools to track the activities. As a task flowed through various statuses, the team could follow this visually and take proactive action whenever necessary. The collaborative planning system allowed greater communication between trades and identified opportunities to improve the workflow in each area.

Using the data provided by VisiLean, opportunities for improving the installation process were identified. By using the data collected by VisiLean, the production process was continually improved as there was a rich source of live information. Bottlenecks were identified, material management, lobour allocations and potential safety issues were identified. This allowed the teams to collectively improve their productivity and streamline the installation process. This resulted in a 30% time improvement from the first data hall installation to the fourth data hall.

Without the management system integrated into the solution, the module design alone would not have delivered the actual benefits realised from deploying a complete construction system. Such a solution would not have been possible without a fully committed leadership team that can spread an infectious appetite for change, continual learning and a clear passion to exceed the expectations of the customer.

CONCLUSIONS

This project attempted to set the standard for data centres across the globe and is seen in the eyes of the customer as the benchmark site for construction excellence. The project aimed to use leading edge innovation as it tried to encapsulate a construction solution going beyond design, to include, product, process and performance management. It is a systematic solution that achieved significant benefits through collaboration and active engagement of the entire supply chain. It is one of the first projects of its kind (in terms of size and complexity) globally to implement a cloud based production planning and tracking system that integrates the Lean processes with BIM in form of VisiLean. Ultimately the solution has delivered a project safer, quicker and to a higher quality, whilst creating a better working environment. Some of the benefits measured as part of the implementation were; i) 75% reduction in working at height, ii) 60% reduction in defects, iii) 43% improvement in program efficiency, iv) 45% reduction in labour spend. Additionally, the team was able to reduce transport and congestion on site and improve real-time project transparency. The use of an electronic tool rather than physical sticky notes reduced the meeting preparation and reporting time and data integrity. Finally, the consistent data collected at the work face helped with continual improvement processes.

While the team recognises many improvements over traditional last planner implementation, there are future improvements that can be achieved to further enhance the production management efficiency. The time and effort needed to connect the plan activities to the model can be reduced by introducing an automated linking process between the model and the plan. Managing resources at the ground level is crucial and the electronic last planner system such as VisiLean can be further enhanced by introducing bottom-up resource management where labour, material, equipment and other resources can be planned and tracked in various production stages.

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