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ORIGINAL RESEARCH

Streamlining production management in construction projects with ICT

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Abstract The research aims to demonstrate the role of BIM and construction management tools as Information and Communication Technology (ICT) in enabling efficient production planning, monitoring, and control, which helps streamline construction project delivery. The research demonstrates the importance of effective communication through efficient information management by deploying digital technology that helps overcome inherent inefficiencies and wastes in the construction management processes. The research follows a case study-based approach to highlight the success of deploying ICT for efficient production management through improved collaboration and communication on an Instructional Building project in California. The research demonstrates the success of ICT in enabling efficient production planning by allowing accurate visualisation of the sequence of works to be executed. With accurate and timely updates from site, multiple trades have been able to communicate effectively, thereby enabling effective control of any issues or deviation. The result was a 6-weeks early completion of the project than initially planned. While ICT has played a crucial role in streamlining construction project delivery over the past few decades, this research dives deeper into understanding where the improvement stems from, i.e., the quality of information offered by technology and its best use towards driving efficiency and collaboration within the project teams. Inefficiencies are common across the construction industry stemming from inaccurate project planning and control. With ICT and its efficient deployment, project teams can define accurate production sequencing, visualise the flow of work, and take proactive decisions to control the impact on schedule. The research provides process-based key insights by focusing on the critical aspects of ICT for data visualisation, data sharing, and data analysis, that helped take informed planning and control decisions for efficient production management for successful early completion of the project.

Keywords Construction management · Information & communication technology · Building information modeling (BIM) · Lean construction · Production management

1 Introduction

Information Communication Technology (ICT) is termed as the use of various forms of tools for storing, transferring, and analysing data [1]. Application of ICT in sectors like manufacturing and engineering has progressed at a fast pace [2], however the construction industry still faces challenges in adoption of technology due to various factors, primarily stemming from a lack of understanding and knowledge of ICT adoption [3].

Construction technology has grown remarkably over the past few decades helping improve the way industry players manage information, beginning from Computer Aided Design (CAD) to creating 3D BIM models, Virtual Design and Construction (VDC), and Common Data Environments

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(CDE) in various forms addressing the fundamental requirements of communication and collaboration between the various stakeholders [4, 5, 6]. However, the realisation of direct benefits from technology has proven to be challenging due to the complex and unique nature of construction projects [7].

Companies adopting ICT aim to enhance decision making and automate their workflows to help improve their project delivery and performance [8]. Application of ICT in construction projects has resulted in several benefits across all the phases of the project. The benefits achieved are from effectively managing design revisions, automating the project management processes by reducing the repetitive tasks and mistakes, and the timely transfer of information between teams [8, 9].

Any tool or technology newly adopted by an organisation is expected to bring a change in the way the complex information is managed towards project delivery practices. ICT has proven to be an enabler for managing projects more efficiently by improving the coordination and integration between project teams and helping communicate the information required at the right time to the right people. However, studies have shown that technology alone has not been successful in bringing the benefits as expected. The fundamental aspects of how the information flows and the quality of information provided by the project teams govern the efficiency of ICT in improving construction project delivery [9, 10].

Although benefits of application of ICT in construction have been evidenced by previous studies, the industry is still at a nascent stage in the adoption of technology. The research here highlights the important aspects of ICT that have enabled effective communication and collaboration between the project teams towards efficient production management through a case study of an institutional building project.

2 Background

The advancement in the application of Building Information Modelling (BIM) in the construction industry has proven to be beneficial throughout the project lifecycle [11]. Lean Construction focuses on waste minimisation, value generation and creating a culture of continuous improvement, driven by enabling flow that facilitates waste reduction, and generating value at each stage [12]. The integration of lean construction and BIM have furthered the benefits realised from deploying ICT on construction projects across the globe [13].

The Last Planner® System (LPS) has a proven track record of enabling efficiency and reducing variability in the production process [14]. The goal is to reduce variability through a commitment-based approach to balance the release of work with the ability of the team to execute it realistically on-site [15].

The need for integrating BIM with the production planning and monitoring systems like LPS is realised to improve information exchange between teams [16]. From the mapped interactions between BIM functionalities and lean construction principles by [13], the most functional interactions expected from BIM are–aesthetic or visual capabilities, coordination between multidiscipline models, 4D visualisation of construction schedule, and communication with the help of product information. Evidently. integrating BIM models with production management systems can help streamline and standardize the production schedules with relevant building and the site information [17].

3 Literature review

3.1 ICT & process management

Information management is complex in construction projects due to the fragmented nature of the industry. Although not all information systems have proven to be effective, those which have enhanced collaboration within projects have proven to be successful with the support of changes within the organisation's processes [18].

[19] highlight the importance of two kinds of information flows – one that helps in accurate planning decisions, and the other that helps take informed project control actions. However, application of information systems does not guarantee benefits if they are applied in silos and not integrated within the overall project workflows.

[9] elaborate on the various ways ICT is deployed in construction and the challenges of financial, social, and cultural aspects associated with its adoption. Building on these challenges, [20] emphasises on the need for a structured approach to adopt any new processes or tools in organisations. Strategic initiatives, combined with cultural and managerial changes in any organisation play a major role in ICT adoption [21].

3.2 ICT to enhance collaboration

[22] highlight the need to capture informal information with the help of an ICT enabled knowledge management application, that offered a common social collaborative platform that was easy to use and enhanced information sharing in a complex and fragmented set up.

[8] have evidenced improved coordination and information exchange, and efficient management of BIM data through automation to avoid repetition of tasks within

various projects using an integrated deployment of ICT across multiple design disciplines.

ICT has the potential to overcome challenges to interdisciplinary integration, which acts as a crucial factor to realising value from its adoption [8].

3.3 Integration of lean and ICT

Emerging ICT tools that enable lean workflows in construction projects have been explored by many to resolve the issues of communication and information sharing. [23] highlight the use of ICT in being valuable to lean workflows by improving information flow. Cloud-based tools have been deployed and tested with project teams that enhanced integration of the supply chain and provide real-time information for better control of the project [24–26].

[27] have explored the use of integrated web services to improve the coordination between project stakeholders, by optimising information flows and in turn enabling lean implementation on the project. [28] have developed a Lean-IT tool to support customisation of housing units through automation that helped reduce considerable lead time, minimise errors, and enhance communication on the project.

Computer Advanced Visualization Tools (CAVT) have been successful at reducing production variability and uncertainty [1]. Virtual Building Technologies (3D/4D CAD) have been deployed for quick review of design alternatives for stakeholders to take well-informed design decisions [29].

[30] have studied the impact of integration of lean principles with VDC processes to help improve construction project delivery. Lean integrated with BIM has enhanced production planning and control process on a data centre project where the team was able to achieve significant reduction in defects and labour spend, and increased program efficiency [26].

3.4 People-process-technology

[1] establish the main elements of ICT in construction – People, Processes, and Tools, and the importance of understanding and developing the relationship between these components to enable efficiency in construction processes.

Lean Project Delivery System (LPDS) [31] provides a structured approach in terms of processes to streamline project delivery. VDC tools and technologies help enhance project performance by supplementing and enabling these process [32].

The fundamental challenges in construction projects are deep-rooted within the nuances of the interactions of project teams and the tools and processes adopted for project delivery [26]. Business processes and information technology are closely associated, and better results can be achieved by addressing them in an integrated manner [33]. Interactions between the project teams are necessary to implement any tool that enhances collaboration [22].

[34] define “wicked” problems as those projects which involve complex and dynamic groups of participants where decision making is critical and problem solving cannot happen in isolation. For this, they emphasise on the flow of reliable and accurate information, rather than tracking and monitoring of activities.

ICT applications cannot be seen as a primary driver to improve project performance. The fundamental production processes need to be set, where ICT applications can enable improvement in the information flows in the overall process, reinstating the need for an integrated framework of people and process to address the challenges of the construction industry [7].

4 Research methodology

The research follows a case study methodology where the authors were involved throughout the implementation of lean processes and system deployment on the project.

The research begins with setting the context through a detailed literature review that highlights the importance of accurate information exchange and efficient communication in the construction industry, and the role that technology plays in making the process more streamlined and effective.

This is followed by a detailed review of the project where the team has delivered early completion of the facility through the effective deployment of ICT and process-based improvements. The case study focuses on the critical success factors contributed by the inclusion of ICT for streamlining the project delivery workflows, as compared to the challenges to effective information exchange and communication through conventional methods.

5 Case study

5.1 Project Background

The project is an Instructional Building, part of a University Campus in California. The project is around 76,000 sq. ft. in overall area, which also includes a Central Plant Unit (CPU) building. The Instructional Building is a 3 floors structure, divided into various 4 zones (A to D), each housing a set of lecture halls, corridors, meeting rooms and service units. The entire structure surrounded an open-to-sky central courtyard.

The General Contractor (GC) was responsible for delivering a ready-to-inhabit facility to the client, which meant that their scope involved everything from the ground-works, all the way to the finishing of the interior spaces. The primary construction of the building included concrete foundations and steel framing of the entire shell and core, complete with inner partition walls, external cladding, roofing and integrated with MEPF for the entire facility. To deliver the complete scope of work, the project included numerous specialised sub-contractors (also referred to as 'trades') participating through the various stages of execution.

5.1.1 Production management

One of the primary aspects of production management was to enable collaborative planning with the trades, which was conventionally being done with the help of sticky-notes on the wall by their superintendents and specialised sub-contractors. For this, the GC would draft a high-level schedule on Oracle® Primavera P6 which would act as a reference to pull detailed work to the target milestones. During this collaborative planning session, the specialised trades would bring in their experience to breakdown these high-level activities into a finer level of detail to define the specific activities to be executed.

This sequence of activities would be recorded on spreadsheets and then recreated in the master P6 schedule. This would be the responsibility of the project planner and proved to be quite a time-demanding exercise. The recreation of production in this manner had scope for human error, potentially leading to dilution of the information in some cases.

5.1.2 The key challenges

The project had a few challenges through its development, the most significant being the repercussions of the COVID-19 pandemic that brought work to halt for a considerable duration of time. This meant that the team had to strategise the planning carefully upon their return, to ensure that the substantial completion date remains unaffected, by delivering and executing a programme that could cover up the gap of no work on site.

The collaborative planning sessions would take place in a closed room with the suppliers and the superintendents working with the master schedule to derive lookahead plans on a board. This manual approach to pull planning posed a major setback when accommodating the COVID restrictions of physical proximity in gathering spaces; communications between teams had a direct impact.

In terms of progress monitoring, the team would spend hours in updating schedules by taking updates from site. When working on the recovery plan to bring the project up to pace again, this approach was seeming to be in vain. The project team ended up constantly trying to chase the schedule, rather than being proactive in resolving issues.

Conventionally, the team would rely heavily on extracting project information from physical copies of drawings. The collaborative planning sessions would be held in trailer rooms with a number of these marked-up drawings put up on the walls for reference (Fig. 1). The trades would be required to physically collect and communicate a lot of this information informally, without having a clearly documented reference before or after the meeting.

To define efficient flow, it is important to clearly understand the work at hand. For this, accurate information is required about design and site conditions. This helps the trades understand the requirements of the job, as well as the physical conditions of the site that will hinder them from executing the work. While the project design had been developed using BIM as the platform and the project team had access to these BIM models of various design disciplines hosting such information, they were not being deployed for production planning and control.

5.2 The deployment of ICT

Considering these challenges, the team started to look at solutions to enhance the deployment and execution of a recovery plan while working through the new COVID restrictions. The obvious route was to go digital and overcome most of the limitations offered by their existing manual workflows, for which the GC adopted VisiLean, a cloud-based construction management tool, to drive lean production management workflows.

5.2.1 Single-source-of-truth

With VisiLean, the team was able to merge the master P6 schedule with the bottom-up production planning following the Last Planner® System, to ensure that information is captured and communicated on one-single platform. VisiLean allowed the team to break their P6 schedule into greater detail with the input from the specialised trades. The information was disseminated across the team by ensuring access to all participants of the project, rather than isolating them from it.

All activities that have blank fields under the WBS ID column in Fig. 2 below show the detailed tasks created by the team on VisiLean, based off the high-level activities imported from the P6 schedule.

As a lean-BIM integrated tool, VisiLean allowed the team to add their BIM models as well to the cloud, making it a Common Data Environment (CDE) for all production

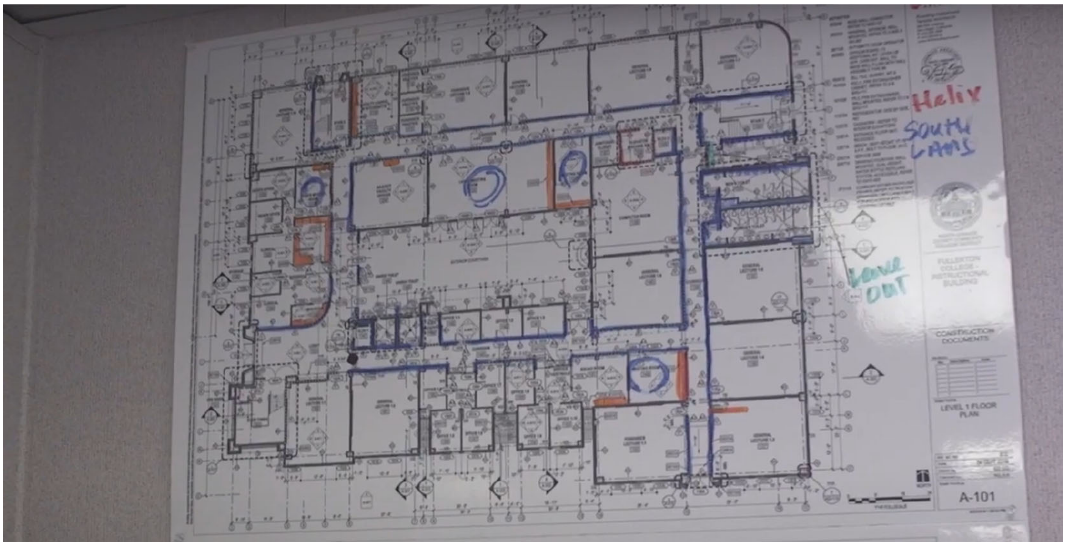


Fig. 1 Drawings marked-up and pinned on trailer walls for discussion

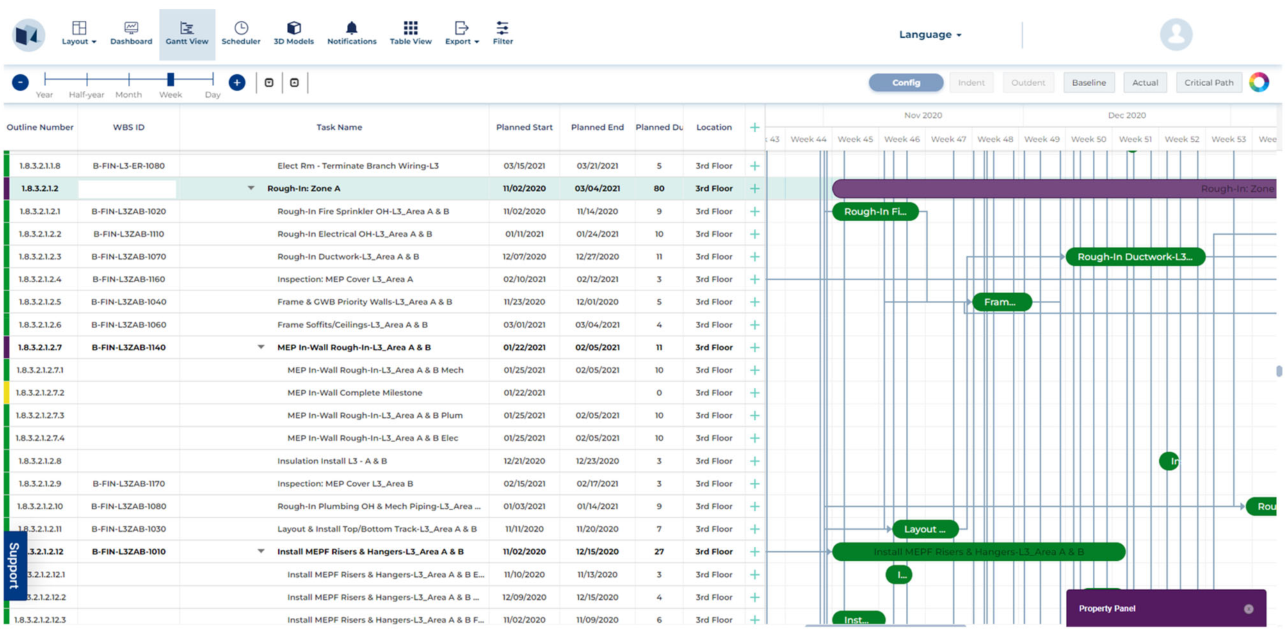


Fig. 2 Snapshot of project gantt view highlighting tasks breakup from P6

related information (Fig. 3). As a construction management system hosting planning and production information, the capability of supporting BIM greatly enhanced the inclusion of these models in the execution process, which were earlier not being deployed for production decisions. The inclusion of design in production management through BIM visualisation amplified the adoption of the tool considerably, with more people relying on the information shared on the platform and the ease with which it would read to them. The team started to show a switch from a 2D drawings-based approach to one of relying on 3D BIM for discussing production details.

5.2.2 *Information for efficient production*

Efficient production planning and control involves a careful understanding of the facility, which is supplemented by product information – design, specifications, site-conditions, vendor details, etc. BIM Models are an efficient and rich source of this information. However, it is important for technology to allow for the information to be shared and read easily by the team for it to be efficiently deployed for production decisions.

The models were populated with accurate space information that allowed the teams to go down to the detail of

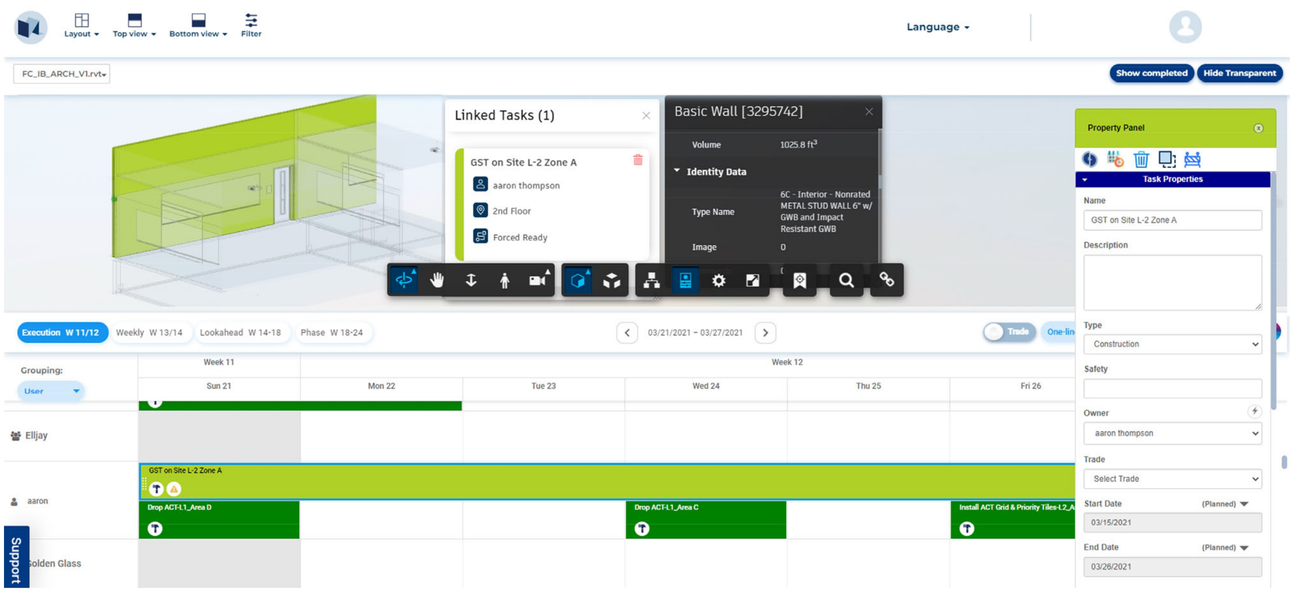


Fig. 3 BIM Model with production assigned to last planners®—VisiLean

task-based planning of each section of a location. Figure 4 below highlights the designed space "Women's Toilet" at "Level 2", which is then linked to the activity called "Toilet Rooms: Zone A" under "Level 02: Interior Finishes & Closeout" WBS. While the production plan and BIM model are two completely separate data-sets, VisiLean as a lean-BIM integrated tool allowed the team to merge this information on a common platform for trades to collaborate towards effective discussions about the production sequencing for the interior finishes for this space.

Planning in greater detail as you get closer to the job is critical to minimise inefficiencies during execution on-site. The detail comes from having reliable and up-to-date information about the job to be executed, the conditions of the space, the predecessor to your activity that is responsible for handing over the space, and the external conditions of the project and site.

With teams capturing photographs from their phones on-site using the VisiLean mobile app, this information would get uploaded to the CDE in real-time (Fig. 5). With the activity already linked to this space in the BIM model, trades could visualise the reality-capture, i.e., the exact condition of the site as-on-today, the intended design from BIM, and any other critical information supplied to the task.

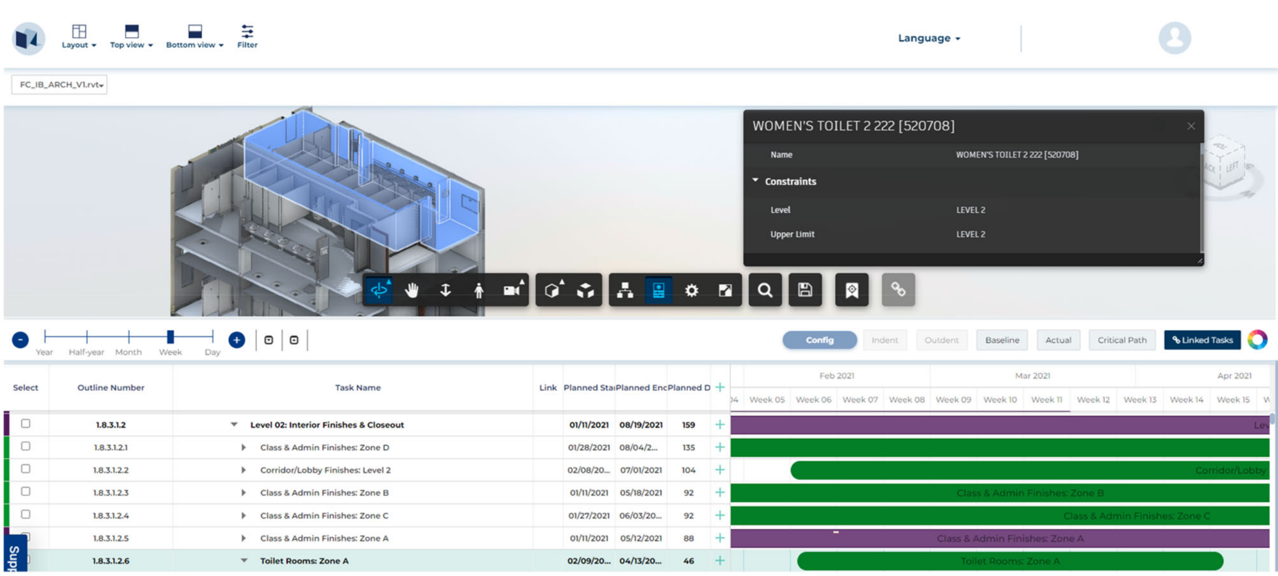


Fig. 4 Location-based information captured through BIM and VisiLean

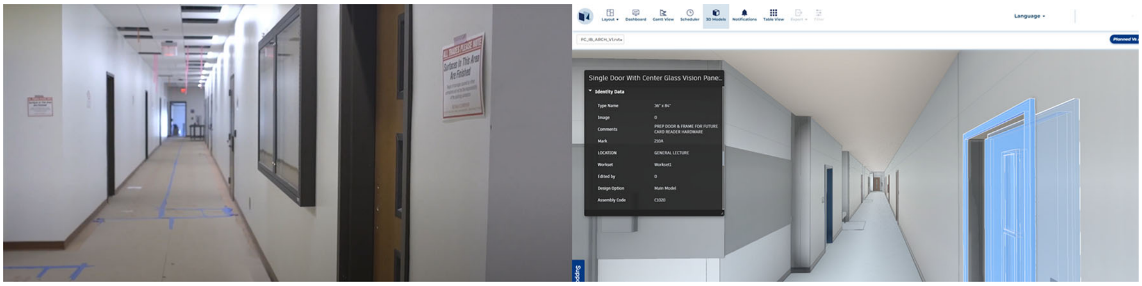


Fig. 5 Site-photograph alongside design information from the BIM Model

5.2.3 Real-time information

With the VisiLean mobile app, the teams on-site were able to give live updates to the tasks being executed (Fig. 6). This ensured that the trades were always up-to-date with the status of works on the ground, thereby ensuring that they are ready with their preparation on-time. This significantly reduced the time wasted in waiting for the job-site to clear and made the handovers more efficient.

The information is also supplied to the teams on-site in the same way, with any change in the intended planning being informed to the person executing the job live to avoid any misinformation between the teams (Fig. 7). With clear communication, the job was executed more efficiently, considerably reducing the rework of tasks executed, as well as quality issues.

These updates were transferred directly to the BIM model through the linking of the production plan and the BIM Model elements. This way, the real-time status updates were reflected on the model elements with the same colour-coding of the task status on VisiLean (Fig. 8). Any issues were visually read by the team with complete clarity to take informed control decisions that helped save critical time. Conventionally, the updates were communicated via a chain of events that would end up delaying this information, which resulted in not only delayed corrective action, but in most cases, it would be built on inaccurate information that would considerably impact the results of the control measures.

5.2.4 Connected remotely

With COVID, teams had to ensure minimum physical crowding on-site. For this, the teams would connect remotely as far as possible through online meeting tools. During this time, having a single-source-of-truth proved immensely beneficial for the teams to review and discuss the production planning (Fig. 9).

VisiLean allowed teams to visualise the work executed, as well as its effect on the work to follow in the weeks to come. This enabled the teams to voice their concerns and provide suggestions on the flow of work seen in their look-ahead. Having this data on one platform helped the teams collaborate over planning decisions with ease, with people even connecting directly from the job-site.

5.2.5 Data for continuous improvement

Driving efficiency in production management is a cyclic exercise, rather than a one-time approach. Implementing strategies for improving production requires a feedback loop, that is built on learning from what worked, and what did not, and working on the shortfalls to improve the next cycle of production.

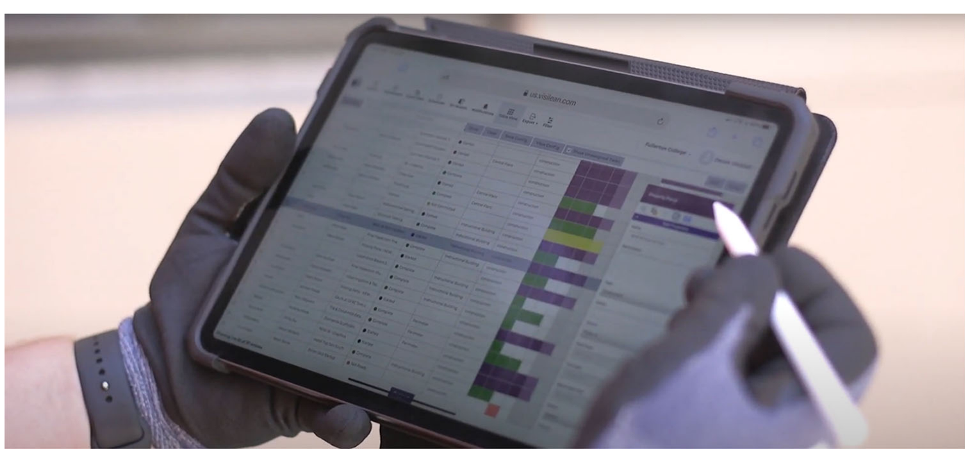
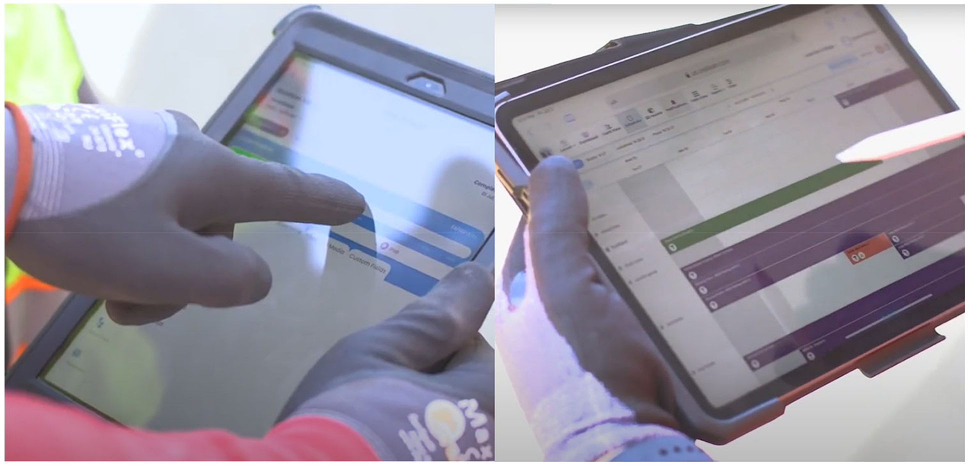


Fig. 6 Teams on-site giving updates on work progress in real-time using VisiLean

Fig. 7 Teams reviewing information on the ground in real-time using VisiLean



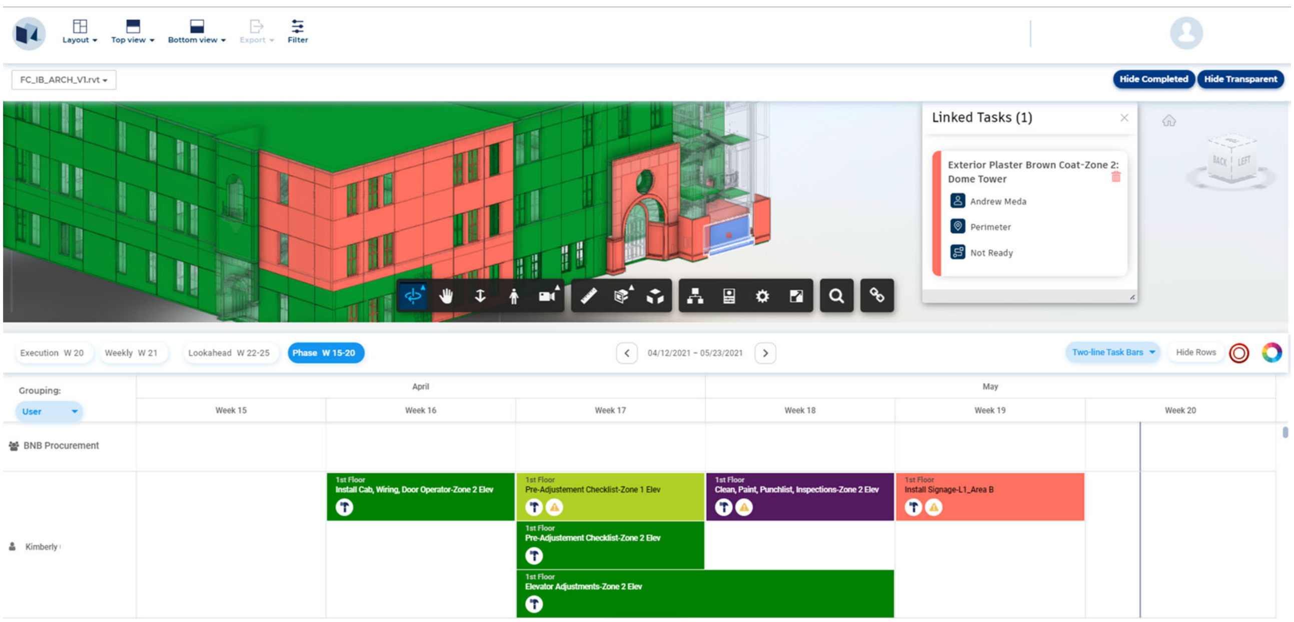


Fig. 8 Reviewing the live update of work progress on the BIM model

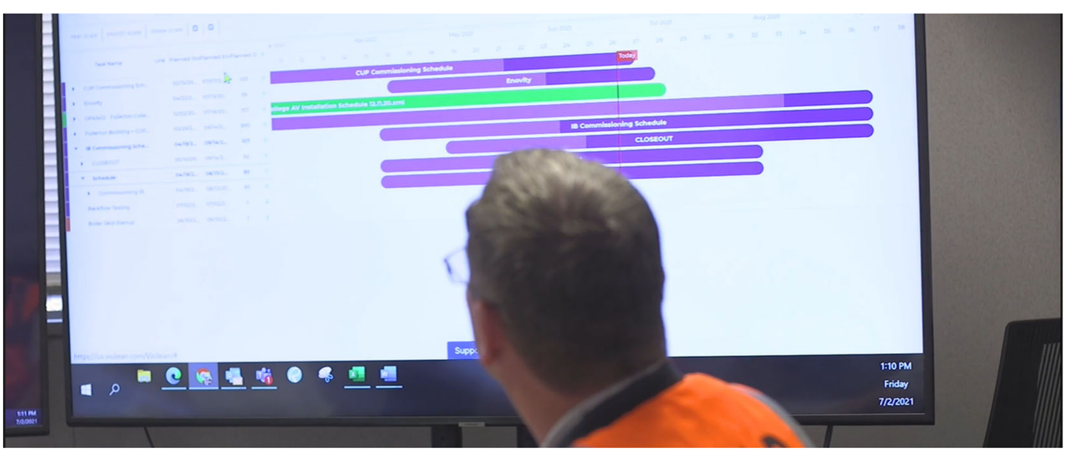


Fig. 9 Teams connected remotely–Reviewing project schedule on VisiLean

The benefits realised on this project have been a direct outcome of constantly improving and upgrading the production management process, with the help of data from the ground that was recorded and provided by VisiLean. This data was presented in the form of Percent Planned Complete (PPC), a metric of the Last Planner® System that provides a clear review of the team's performance against their weekly work commitment. The PPC was reviewed by the teams collectively during the weekly production control meetings. Figure 10 shows an average of 9 weeks PPC captured through the months of March to May 2021, with each team's performance clearly highlighted.

For any deviation from the planning of the work, the team was required to provide a reason for variance, with the intent to collectively learn from and work on these inefficiencies. Some examples of this information have been captured below in Fig. 11 from VisiLean, where the impact of "Material" and "Manpower" has been highlighted as the reasons for non-completion of the activities in their planned week.

6 Benefits

With the accurate deployment of ICT on this project, the team was able to regain control on the production management process efficiently while working through the immediate ramifications of COVID. With the adopted Lean-BIM integrated tool, the team was able to not only recover the site-shut period, but also manage to complete and deliver the project 6 weeks ahead of schedule.

Through ICT driven collaborative planning, the team was able to achieve staggering results in terms of plan reliability. On this project, the team was able to consistently drive gradual improvement in their PPC as the implementation of ICT progressed. The snapshots below in Fig. 12 show the caparison between the average PPC of 9 weeks through the months of March to May between 2020 and 2021. In 2020, the team was at a PPC of 58%, with a considerable number of commitments being missed. In comparison, the team was able to achieve a staggering PPC of 94% in 2021, with gradual improvements over the one-year period.

Another key thing to note here is the absence of trade participation during the initial stages of implementation of ICT (from the evident lack of "Organisations" in the PPC record of 2020). As the adoption progressed and the participation grew from the project teams, the quality of information captured by the tool improved multi-folds, leading to accurate and informative data for the teams to review (Reasons from Variance in the PPC record of 2021). This was done through individual PPC review of each trade, as well as having clear reasons for variance documented for learnings and continuous improvement.

The results attained on the project are a direct impact of the efficient production planning, monitoring, and control, that the team was able to achieve by getting accurate information about the facility, timely and reliable information on the project status and environment and being able to disseminate that information efficiently amongst the project teams through a common data platform that allowed for effective participation and clear communication. This has been evidenced by the successful participation of every single trade on VisiLean.

Despite COVID limiting the conventional ways of communication between project teams, the project was able to control the repercussions on project delivery through effective collaboration using ICT. In fact, communication through technology (and mobile devices) has created a transparent environment by providing complete work clarity to the trades, thereby building a culture of trust within the project team.

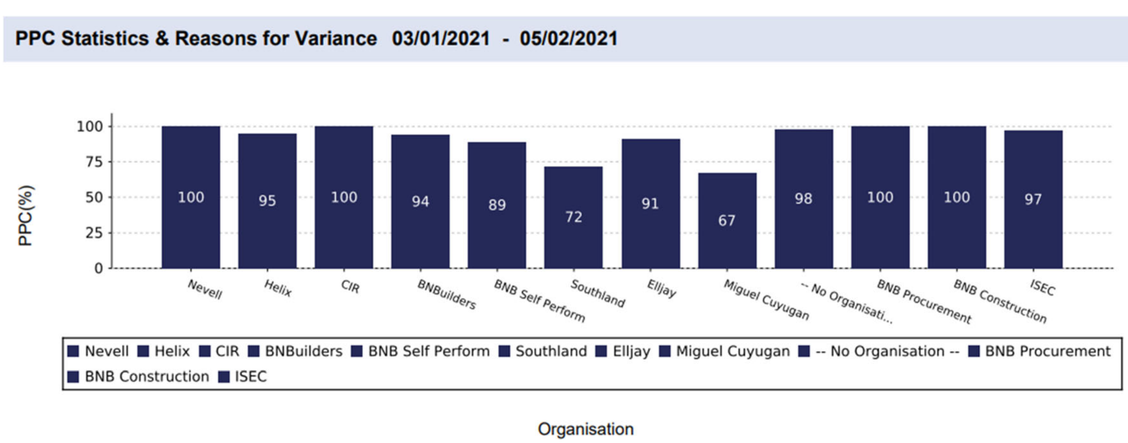


Fig. 10 Summary of average PPC over 9 weeks for each trade on the project

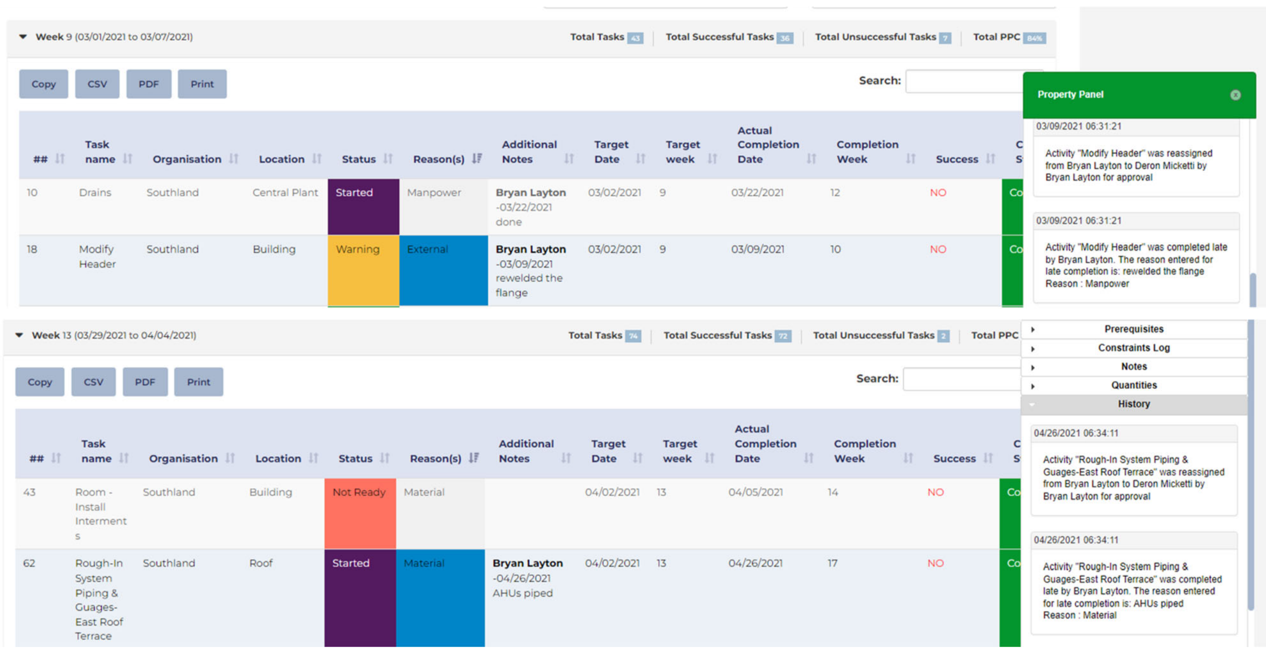


Fig. 11 Reasons for variance captured on VisiLean to provide data for improvement

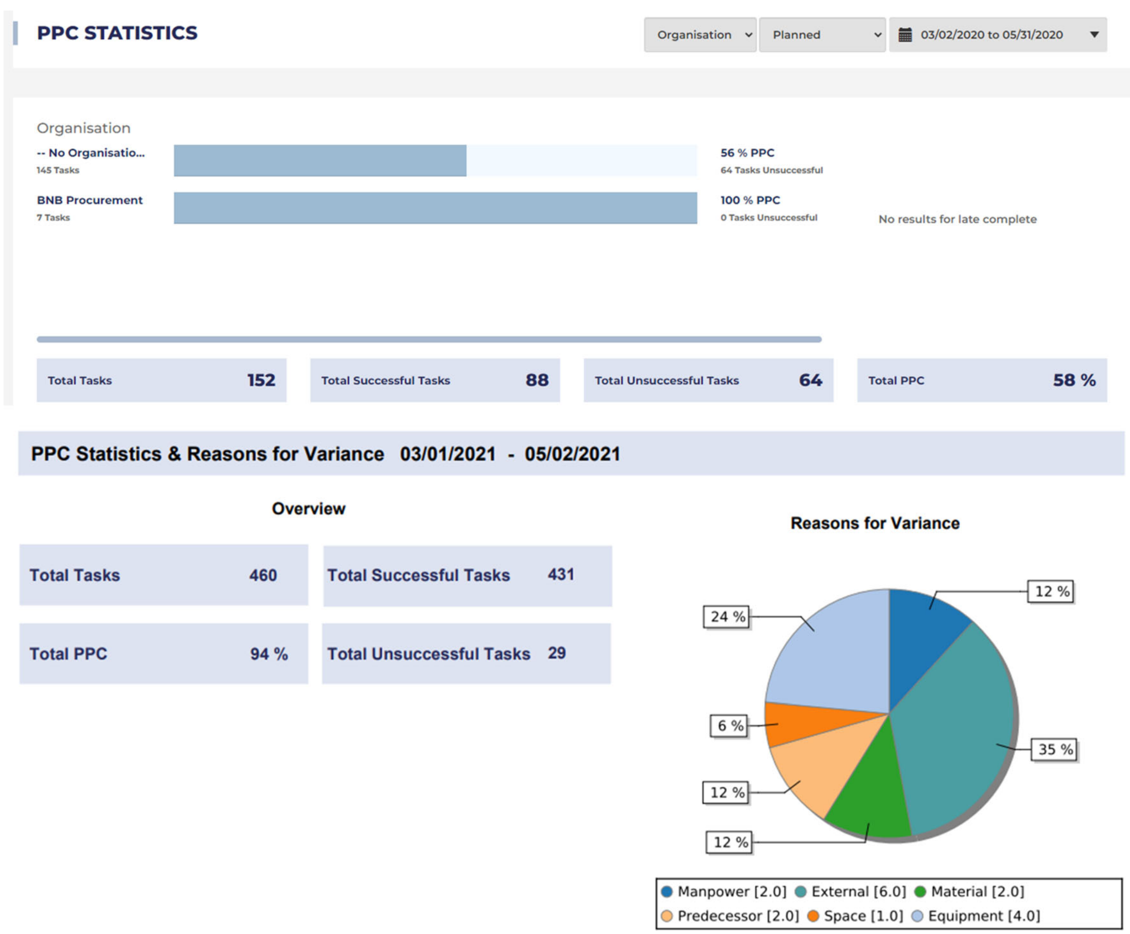


Fig. 12 Summary of PPC for 9 weeks–A comparison of year 2020 vs 2021

7 Conclusions

ICT has been advancing as an enabler in the construction industry to improve project delivery by enhancing communication and integration between the teams. Although there are several tools and technologies that are being used by different projects across the industry, the quality of the information captured and exchanged has proven to be one of the major factors that drives improvements.

The authors demonstrate in detail the role of application of BIM and construction management tools as ICT on a project where existing production management processes proved to be limiting and significantly hindered by the COVID-19 pandemic. With the help of an integrated tool that merged master scheduling with bottom-up collaborative planning and BIM visualisation, the team was able to streamline their production planning and control methods through enhanced collaboration and effective communication. The application of ICT significantly improved the capture of status and progress of work on the ground, which helped streamline the capture and review of production information.

Having situational awareness of the immediate ramifications of the global pandemic helped the team react in a timely manner towards adopting digital tools for production management to ensure that the effect on schedule is controlled at the earliest. The key factors for achieving significant benefits from ICT on the project stemmed from making it available to the entire team, populating it with the right information, and enabling the team to read and analyse the data for better production planning and control decisions. The implementation of ICT was coupled with a gradual change in the existing workflows that helped improve the participation by the team and hence, the quality of information being supplied and shared. This combined approach and an increase in the accuracy of the data provided by ICT helped build a culture of trust and collaboration within the teams.

With the data captured in real-time from site, the teams were able to focus on improvement strategies that had evident results on their performance each week which they could collectively review. Here, the study reinforces the importance of aligning technology with the right workflows and culture to achieve efficient project delivery. Benefits cannot be realised through isolated deployment of ICT on a project, without any changes to the existing workflows or collaboration practices. Efficient production management demands clear communication and effective collaboration between teams, for which ICT acts as an enabler. To streamline construction project delivery, accurate and timely information must be provided for project teams to adopt an effective and proactive approach towards decision making.

References

1. Rischmoller L, Alarcón LF (2005) Using lean principles as a framework to study information technology in construction. 13th International group for lean construction conference: proceedings, 171–178
2. Smith P (2014) BIM Implementation – Global Strategies. Procedia Eng 85:482–492. https://doi.org/10.1016/j.proeng.2014.10.575
3. Fosse R, Ballard G, Fischer M (2017) 'Virtual design and construction: aligning BIM and lean in practice' In: 25th annual conference of the international group for lean construction. Heraklion, Greece, 9–12 Jul 2017. pp 499–506
4. Samuelson O (2002) IT-Barometer 2000 – the use of IT in the Nordic construction industry. Electronic Journal of Information Technology in Construction (ITcon), 7, 1–26, available at: http://www.itcon.org/2002/1
5. Issa RRA, Flood I, Treffinger B (2003) Assessment of e-business implementation in the US construction industry. E-Bus Constr 8(May):248–265. https://doi.org/10.1002/9781444302462.ch15
6. Taş E, Pinar IC (2007) A survey of the use of it in building product information acquisition in Turkey. J Info Tech Constr 12:323–335
7. Bhargav D, Lauri K, Mike K, Sven B (2008) A critical look at integrating people, process and information systems within the construction sector. Proceedings of IGLC16: 16th Annual conference of the international group for lean construction. 795–807.
8. Fischer M, Kunz J (2004) The scope and role of information technology in construction. Doboku Gakkai Ronbunshu 63:1–31. https://doi.org/10.2208/jscej.2004.763_1
9. Koskela L, Kazi AS (2003) Information technology in construction: how to realise the benefits? Socio-technical and human cognition elements of information systems, 60–75
10. Tatari O, Castro-Lacouture D, Skibniewski M (2007) Current state of construction enterprise information systems: survey research. Constr Innovat: Info, Process, Manage 7:310–319. https://doi.org/10.1108/14714170710780075
11. Eastman C, Teicholz P, Sack R, Liston K (2011) BIM Handbook Introduction BIM Handbook, a Guide to Building Information Modelling. 2nd edn, 1–29. Wiley, Hoboken
12. Ballard G, Howell G (1998) What Kind of Production Is Construction? 6th annual conference of international group of the lean construction, Guaruja, Brazil, 13–15 August, May, 1–15
13. Sacks R, Koskela L, Dave BA, Owen R (2010) Interaction of Lean and Building Information Modeling in Construction. J. Constr. Eng. Manage 136(9):968–980
14. Ballard G, Howell G (2003) An update on last planner. 11th annual conference of the international group for lean construction, 1–10
15. Koskela L (1999) Management of production in construction: a theoretical view. Proceedings IGLC-7, 241–252
16. Dave B, Pikas E, Kerosuo H, Maki T (2015) ViBR - Conceptualising a virtual big room through the framework of people. Process Tech. https://doi.org/10.1016/S2212-5671(15)00216-6
17. Schimanski CP, Pasetti Monizza G, Marcher C, Matt DT (2021) Development of a BIM-based production planning and control system for Lean Construction through advancement and integration of existing management techniques. Front Eng Manage 8(3):429–441. https://doi.org/10.1007/s42524-020-0105-5

18. Craig N, Sommerville J (2006) Information management systems on construction projects: case reviews. Rec Manag J 16(3):131–148. https://doi.org/10.1108/09565690610713192
19. Dave B, Kubler S, Främling K, Koskela L (2014) Addressing information flow in lean production management and control in construction. In 22nd annual conference of the international group for lean construction: understanding and improving project based production, IGLC 2014 (pp. 581–592). The international group for lean construction. http://eprints.hud.ac.uk/id/eprint/26202/
20. Harstad E, Lædre O, Svalestuen F, Skhmot N (2015) How tablets can improve communication in construction projects. Proceedings of IGLC 23 - 23rd annual conference of the international group for lean construction: global knowledge - global solutions, 391–401
21. Ahuja V, Yang J, Shankar R (2009) Study of ICT adoption for building project management in the Indian construction industry. Autom Constr 18(4):415–423
22. Dave B, Koskela L (2009) Collaborative knowledge management-A construction case study. Autom Constr 18(7):894–902. https://doi.org/10.1016/j.autcon.2009.03.015
23. Cheng T, Teizer J, Migliaccio GC, Gatti UC (2013) Automated task-level activity analysis through fusion of real time location sensors and worker's thoracic posture data. Automat Construct. https://doi.org/10.1016/j.autcon.2012.08.003
24. Azambuja M, Schnitzer T, Sahin M, Lee F (2013) Enabling lean supply with a cloud computing platform - An exploratory case study. 21st Annual conference of the international group for lean construction 2013, IGLC 2013, 815–824
25. Ghossaini BM, Dehaini KY, Alruzz MA, Fakhr Eddine NA, Hamzeh FR (2018) Synclean: An application for improved lean construction practice. IGLC 2018 - Proceedings of the 26th annual conference of the international group for lean construction: evolving lean construction towards mature production management across cultures and frontiers, 2, 1195–1205. https://doi.org/10.24928/2018/0242
26. McHugh K, Dave B, Craig R (2019) Integrated lean and BIM processes for modularised construction - A case study. 27th Annual conference of the international group for lean construction, IGLC 2019, 227–238. https://doi.org/10.24928/2019/0252
27. Dave B, Boddy S, Koskela L (2010) Improving information flow within the production management system with web services. Challenging lean construction thinking: what do we think and what do we know? - 18th Annual conference of the international group for lean construction, IGLC 18, 445–455
28. Martinez E, Tommelein ID, Alvear A (2017) Integration of lean and information technology to enable a customization strategy in affordable housing. IGLC 2017 - Proceedings of the 25th annual conference of the international group for lean construction, II(July), 95–102. https://doi.org/10.24928/2017/0136
29. Khanzode A, Fischer M, Reed D (2005) Case study of the implementation of the Lean Project Delivery System (LPDS) using virtual building technologies on a large healthcare project. In 13th International group for lean construction conference: proceedings (pp. 153–160)
30. Mandujano M, Alarcón L, Dave B, Mourgues C, Koskela L (2021) Understanding the interaction between virtual design, construction and lean construction. 107–115
31. Glenn B (2000) "Lean project delivery system." White Paper #8, Lean Construction Institute, May 1, 6 pp
32. Atul K, Martin F, R Dean F, Glenn B (2006) A guide to applying the principles of Virtual Design & Construction (VDC) to the lean project delivery process
33. Dave B, Appleby C (2015) Case 1- Striving for continuous process improvement - a construction case study. Indian Lean Construction Conference, 14. https://aaltodoc.aalto.fi/handle/123456789/15252
34. Lane R, Woodman G (2000) Wicked problems, Righteous solutions " Back to the future on large complex projects. Civ Eng, 44:1–12 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.1160&rep=rep1&type=pdf