

ENABLING LEAN PRODUCTION THROUGH DIGITAL PLANNING SYSTEMS

Kevin McHugh¹, Patricia Tzortzopoulos², & Emmanuel Manu³

ABSTRACT

Program-driven project environments emphasise adherence to master programmes, often overshadowing flow reliability, transparency, and collaborative problem-solving, which can undermine the Last Planner System® (LPS), particularly during commissioning when prerequisite complexity intensifies. This study examines how deliberately configured digital tools aligned with Lean principles can support—rather than constrain—LPS behaviours during the transition from construction to commissioning. Using a design-science-inspired approach and an embedded qualitative case study of a major industrial energy-centre project in Ireland, data were gathered from surveys, observations, weekly work plans, readiness indicators, and digital planning artefacts. Results show notable improvements in planning reliability, evidenced by increased Planned Percent Complete (PPC), as enhanced readiness processes reduced the commissioning readiness gap. Once readiness-first routines were integrated into digital work-feedback systems, this gap became more visible. The study identifies sociotechnical interventions—including readiness dashboards, structured digital feedback mechanisms, and improved task definitions—through which Lean principles shaped digital tool use. These interventions reframed digital reporting from programme compliance toward shared diagnosis of constraints, supporting broader participation and psychologically safer conversations. Rather than offering a full framework, the research provides empirical insights to guide practitioners configuring digital planning systems and inform future Lean-digital integration.

KEYWORDS

Last Planner System, digital visual management, psychological safety, behavioural change, commissioning readiness.

INTRODUCTION

Construction projects frequently suffer from fragmented communication, adversarial interactions, and uneven information flow, which undermine predictable work progression and programme performance (Ballard & Howell, 2003). Programme driven management approaches can amplify these problems by prioritising milestone adherence over understanding variability, interdependencies, and practical readiness conditions (Fewings et al., 2019). In such settings, teams may hesitate to raise constraints or challenge optimistic assumptions, reinforcing cultures that reward compliance rather than collaboration (Moradi & Sormunen, 2023).

¹ Consultant/Researcher/McHugh, Lean construction, Ireland, Nottingham Trent University U.K. mchughleanconstruction@gmail.com orcid.org/0000-0002-6017-4585

² Professor, Department of Architecture, School of Architecture, Design and the Built Environment, Nottingham Trent University UK, patricia.tzortzopoulos@ntu.ac.uk, orcid.org/0000-0002-8740-6753

³ Associate Professor, Department of Construction Management, School of Architecture, Design and the Built Environment, Nottingham Trent University UK, emmanuel.manu@ntu.ac.uk, orcid.org/0000-0002-9002-3681

Lean Construction offers an alternative perspective centred on reliable flow, collaborative planning, early constraint removal, and continuous learning (Ballard 2000). The LPS operationalises these ideas through routines such as lookahead planning, make-ready, and weekly work planning. Nonetheless, the adoption of LPS within organisations structured around programme logic presents significant challenges. Factors such as unclear task specifications, protective reporting practices, and digital platforms primarily designed for monitoring purposes may undermine the efficacy of LPS (Ballard & Tommelein 2016).

Despite the availability of digital LPS platforms, little empirical research examines how readiness-first digital configurations shape planning behaviour during the transition from construction to commissioning in programme-driven environments. This study addresses that gap. This paper asks: How can digital tools be configured, guided by Lean philosophy, to support LPS behaviours during the transition from construction to commissioning in programme-driven environments? The contribution is empirical: it documents how a Digital Lean Production system (DLPS) was designed and used to foreground readiness, surface constraints, and support collaborative problem-solving during commissioning—a phase that is often underexamined despite its high interdependency and documentation demands (Power et al. 2021).

In this paper, the term *programme* is used throughout (equivalent to what international literature often refers to as the project *schedule*).

LITERATURE REVIEW

Lean Construction conceptualises production as a flow-oriented system in which reliable handoffs, proactive constraint removal, and realistic commitments are central to performance (Ballard, 2000; Ballard & Howell, 2003; Koskela, 2000; Koskela & Ballard, 2003). Through the Last Planner System® (LPS), these principles are operationalised into collaborative routines such as lookahead planning, make-ready, and weekly work planning. Early implementation work highlighted that achieving these benefits depends on changing how project teams think and act, not simply introducing new tools or procedures (Howell & Ballard, 1998). Subsequent benchmark studies show that while LPS adoption has expanded, it is often applied as a compliance exercise—focusing on meetings and PPC calculation—rather than as a production-control system oriented toward flow reliability (Ballard & Tommelein, 2021). Empirical work on collaborative planning similarly emphasises that LPS only adds value when it genuinely supports joint constraint surfacing and realistic commitment-making (Daniel & Pasquire, 2019; Daniel et al., 2017).

In many projects, however, LPS is implemented within programme-driven organisational logics. Strong milestone pressure, risk aversion, and ambiguous task definitions can push teams toward superficial progress reporting and suppress the open discussion of constraints that Lean production logic requires (Moradi & Sormunen, 2023). These behavioural tensions are reinforced by traditional programme-driven project management, which tends to prioritise adherence to planned dates over understanding variability or readiness conditions. Such approaches can conceal prerequisite failures and coordination gaps until they become critical, masking systemic weaknesses behind apparent programme compliance (Fewings & Henjewe, 2019). Persistent adversarial dynamics and escalating conflict behaviours are also reported when expectations and responsibilities are unclear, underscoring the need for greater transparency in production information (Yiu & Cheung, 2006). In response, Lean scholars emphasise psychological safety as a precondition for effective collaborative planning: teams only engage in frank discussion of “Not Ready” work and variance from plan when the interpersonal risk of speaking up is low (Edmondson, 1999; Moradi & Sormunen, 2023).

Digitalisation introduces both opportunities and risks within Lean planning environments. Digital LPS platforms can increase visibility of status, prerequisites, and production metrics,

but evidence suggests value depends on alignment with Lean production logic rather than technology alone. Action-research shows that digital visual management can strengthen LPS by improving shared understanding and participation when dashboards and boards support collaborative dialogue rather than programme compliance (Conte et al., 2022; Duan & Schwartz, 2021; Pikas et al., 2022). When configured primarily for monitoring, however, digital systems may reinforce programme-driven behaviours and reduce willingness to surface constraints (Tezel & Aziz, 2017; Calvetti et al., 2020). A systematic review similarly concludes that automation can support flow reliability and proactive constraint management only when embedded in appropriate organisational practices and learning routines (Agrawal et al., 2024).

These findings align with sociotechnical accounts of Lean, which emphasise reciprocal interactions between social conditions (e.g., psychological safety, collaboration, leadership) and technical arrangements (e.g., information representations, task structures) in shaping planning performance (Gamage et al., 2025). Digital transformation maturity studies likewise indicate that social and operational readiness are as critical as technical capability for realising value from digital tools (Fernandes et al., 2024). This matters during the transition from construction to commissioning, where interdependencies, documentation, isolations, inspections, and access constraints are often weakly represented in programme-driven schedules, and where commissioning and qualification delivery have been shown to benefit from disciplined LPS application (Power et al., 2021).

Lean Construction 4.0 research therefore argues that digital visual management should prioritise situational awareness and readiness visibility to support decentralised decision-making and early constraint removal, rather than retrospective performance tracking (Görsch et al., 2026). Taken together, the literature indicates a gap in empirical understanding of how readiness-first digital configurations shape LPS behaviours and psychologically safer constraint surfacing during commissioning transitions, motivating the present study.

METHODOLOGY

This research adopted a **Design Science Research (DSR)-inspired** approach combined with an embedded qualitative case study (March & Smith 1995). The objective was to design, deploy, and evaluate a sociotechnical artefact—the DLPS—intended to reinforce Lean behaviours in a programme-driven commissioning context.

DSR stages and artefact logic: The intervention followed iterative DSR stages adapted for practice:

- **Problem diagnosis** — identified behavioural and process barriers to reliable planning (defensive reporting, ambiguous tasks, inconsistent readiness checks).
- **Artefact design and development** — created DLPS elements: readiness-first task templates, embedded prerequisite checks, structured digital feedback loops, visual dashboards, and standardised task definitions. These elements were iteratively refined through weekly cycles.
- **Demonstration and evaluation** — deployed the DLPS within existing meeting structures and evaluated effects using mixed qualitative and quantitative data.

This framing clarifies the artefact’s role: the DLPS is a sociotechnical configuration (tool + templates + routines + facilitation) rather than a single software product.

CASE CONTEXT

The case examines Mace Construct management of the construction and commissioning of a 110 MW data-centre microgrid on a Dublin technology campus. The project integrates dual-fuel engines (natural gas with HVO backup), a 20 MW BESS for load smoothing, and three modular

energy centres delivering up to 30 MW each. Future-ready features include hydrogen-blending capability, CHP-readiness for potential district-heating integration, and rainwater harvesting to reduce mains-water demand.

These interdependent systems created a commissioning environment with tightly coupled electrical, mechanical, and documentation prerequisites. Activities such as isolations, MV cable pulls, energisation, and integrated system testing required highly coordinated sequencing across multiple trades. Combined with strong programme pressures, this complexity provided an ideal context for evaluating how a Digital Last Planner System (DLPS) could support readiness-first behaviours and improve planning reliability during the transition from construction to commissioning.

Beyond the technical complexity, the organisational environment exhibited strong milestone pressure, variable adherence to prerequisite checks, and inconsistent understanding of commissioning requirements among trades. Planning meetings were often dominated by a small number of voices, with defensive reporting behaviours limiting early surfacing of constraints. These behavioural and cultural features created the conditions under which the readiness-first digital intervention could meaningfully reshape planning reliability.

DATA ANALYSIS

Data sources and volumes

Data were triangulated across multiple sources:

- **Survey** — 16 participants (project managers, trade leads, commissioning engineers) to explore planning behaviours and digital adoption.
- **Observations** — 8 weeks, ~25 meetings to capture interactions, constraint discussions, and readiness routines.
- **Weekly work plans** — entries from ~20 trade representatives used to calculate PPC and readiness distributions.
- **Planning artefacts** — lookaheads, readiness flags, and task templates for triangulation.
- **Dashboards and platform exports** — Power BI, VisiLean, and Mural exports to confirm trends.

Table 1: Data sources and volumes

Data Source	Volume	Purpose
Survey	16 participants	Explore planning behaviours and digital adoption
Observations	8 weeks, ~25 meetings	Capture interactions, constraint discussions, readiness routines
Weekly work plans	~20 trade reps	PPC, readiness, reasons for noncompletion
Planning artefacts	Lookaheads, readiness flags	Triangulation and validation
Dashboards & platform exports	Power BI, VisiLean, Mural	Confirm trends and readiness distributions

Qualitative data were analysed using inductive thematic coding. survey responses and observation notes were open-coded to identify behaviours, constraint-handling patterns, psychological safety indicators, and responses to digital interventions. Codes were iteratively

grouped into thematic clusters (programme control, readiness behaviours, digital interpretation, collaboration, learning routines).

Quantitative PPC and readiness distributions were used to triangulate qualitative themes. Member-checking with two stakeholders and an audit trail supported credibility. The survey instrument was informed by the literature review themes (psychological safety, readiness, constraint handling, digital tool use) and refined following initial observations of planning meetings.

Weekly meeting structure and DLPS routines

The DLPS was embedded in an adapted weekly meeting cadence designed to reinforce make-ready thinking and link construction and commissioning workflows. Meetings used DLPS dashboards to visualise readiness, blockers, and commitments. Lookahead planning (3–6 week horizon) required discipline leads to check predefined prerequisites (access, documentation, QA inspections, preceding trades, permits, commissioning requirements). Tasks failing prerequisites were flagged Not Ready and routed into make-ready discussions.

Table 2: Weekly meeting structure and objectives

Day	Meeting	Primary Objectives
Monday	Area Coordination – Externals & Envelope	Sequence and constraints; make-ready confirmation; interfaces with logistics & crane; blockers removed
Monday	Area Coordination – Fit-out Areas	Work plan alignment (6–12 weeks); daily plan readiness; QA/H&S constraints; trades coordination
Monday	Area Make ready needs – Cx Areas	Commissioning prerequisites; RT status; test readiness and resource plan
Wednesday	GC Manager Site Review	Paperwork (RAMS, permits, ITPs) review; make-ready needs for Envelope, Fit-out, Cx for following week; clear actions
Thursday	Last Planner (Owners Briefing)	Owners brief planned activities; confirm constraints cleared; agree WWP commitments for next week
Friday	Control Room – Dashboard Review	Track PPC, priorities, and improvement focus; confirm support needs

Lookahead planning and make-ready process

Lookahead planning formed the backbone of the DLPS intervention. During each cycle, discipline leads reviewed tasks within a 3–6-week horizon, checking readiness against predefined prerequisites such as access, documentation, QA inspections, preceding trades, permits, commissioning requirements, and system-testing dependencies.

Tasks failing one or more prerequisites were flagged as *Not Ready* within the DLPS, ensuring that constraints were surfaced early and directed into the appropriate make-ready discussions. The digital environment improved the consistency of prerequisite checks by

embedding them directly into task creation and updating routines. This process was particularly valuable during commissioning, where prerequisite complexity is high.

The weekly make-ready meeting planning meetings identified interfaces between commissioning and construction activities. The digital platforms allowed teams to co-ordinate Cx activities and to confirm the readiness status. This improved the quality of the weekly plan further by ensuring that planned tasks were communicated and could be effectively managed.

FINDINGS

Behavioural changes associated with the DLPS

Before DLPS deployment, planning meetings were dominated by a few voices, focused on confirming programme status, and relied on informal, ad-hoc constraint resolution. After DLPS introduction, several behavioural shifts were observed:

Table 3: Behavioural changes observed and related project impacts

Previous Behaviour	Behavioural Change Observed	Resulting Project Impact
Programme compliance treated as the main success metric	Teams openly flagged Not Ready tasks during lookahead reviews and Daily/Area Briefings	PPC improved from ~12% to ~64% as commitments became more realistic
Ambiguous task descriptions (e.g., “concrete cores”)	Adoption of clearer, action-oriented task definitions	Fewer prerequisite failures; clearer expectations at handoffs
Reactive constraint management	Earlier identification and allocation of constraints through dashboards	Reduced delays and fewer last-minute escalations
Limited engagement of trades in planning	Wider participation in planning meetings and weekly work planning	Better coordination and earlier identification of cross-trade blockers
Digital tools used mainly for reporting/compliance	Platforms reconfigured to foreground readiness and make-ready needs	Higher transparency, reduced fear of blame, and improved psychological safety

Following the introduction of the DLPS, planning behaviours shifted toward greater collaboration and readiness awareness. Participation broadened as dashboards provided neutral reference points that reduced interpersonal pressure and encouraged wider trade engagement. Teams increasingly reported *Not Ready* tasks, reframing variance discussions around missing prerequisites rather than individual performance. At the same time, clearer, action-oriented task definitions reduced ambiguity at handoffs, supporting more realistic commitments and improved coordination across trades.

Team feedback confirmed that consistent use of the digital production control system improved collaboration: *‘The more information added to the system, the easier it is to collaborate.’* The quality of information directly impacted the production process. Participants also stressed that universal participation and disciplined daily updates were essential: *‘All trades need to buy in, it doesn’t work properly if only a few do it,’* and *‘All need to have the tasks updated daily, it’s not a big job, just requires discipline.’*

PPC TREND AND PLANNING RELIABILITY

PPC rose from approximately **12%** in early observation weeks to **~64%** after DLPS routines were established. This improvement reflected more realistic commitments (promises based on verified readiness) and earlier identification and resolution of constraints. PPC was calculated weekly from VisiLean entries following standard LPS practice: the proportion of planned tasks completed in the week as promised.

The volume of information increased as it became more apparent in the production meeting where teams were working and what capacity was for each team. As prerequisite checks became more consistent and visualised, teams were able to commit to a higher number of **realistic, well-defined tasks**, improving both the **quality** of task definitions and the **volume** of commitments that met readiness criteria.

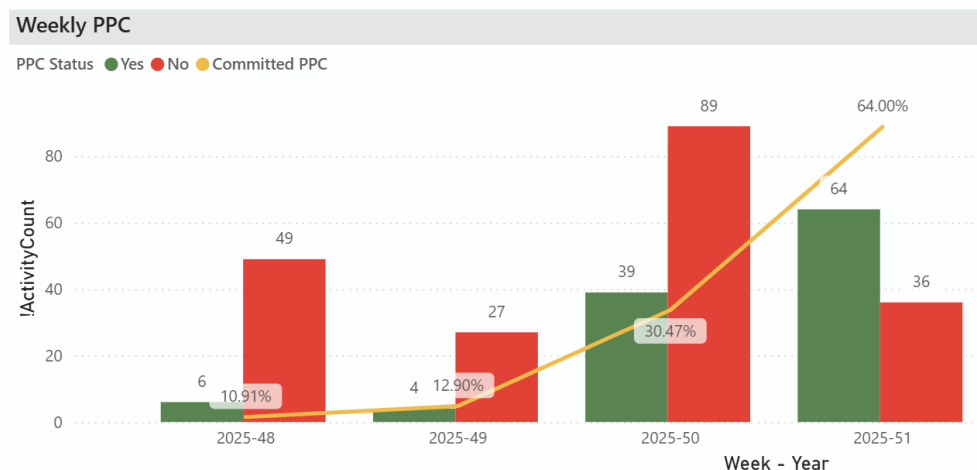


Figure 1: PPC weekly trends

TRANSITION TO COMMISSIONING: BEHAVIOURAL AND ORGANISATIONAL CHALLENGES

The transition from construction to commissioning introduced new behavioural and organisational challenges. Commissioning requires a shift in focus from installed quantities to system integrity, documentation, and quality assurance. Changes in the weekly meeting structure (Table 3) incorporated commissioning readiness checks, make-ready actions, and structured agendas for constraint management. Dashboards and VisiLean views played a critical role in maintaining visibility of prerequisites and ensuring accountability.

However, some teams struggled to adapt to this mindset. Tasks were sometimes marked as “done” from a construction perspective while key commissioning prerequisites—such as completed inspections, test packs, or access clearance—remained incomplete. Interviews indicated that participants initially perceived dashboards as “another layer of reporting,” but over time, as DLPS focused on jointly resolving highlighted issues, these tools were increasingly seen as shared problem-solving aids rather than surveillance instruments.

READINESS GAP DURING TRANSITION TO COMMISSIONING

Analysis of the weekly workplan data revealed a clear readiness gap at the onset of commissioning. A substantial portion of upcoming activities still required make-ready actions, many of which related to MV cable pulls, isolator installations, energisation prerequisites, and documentation checks. While construction tasks were continuing to advance, commissioning work was progressing more slowly because many tasks faced unresolved constraints or lacked sufficient clarity on their specific requirements. This contrast highlighted that, although visible physical progress was being made, a significant amount of commissioning work could not yet move forward due to outstanding prerequisites.

Table 4: Task readiness

Readiness Category	Count (N = 126)	% of Total	Typical Prerequisites Missing / Included
Documentation Not Ready	31	25%	Incomplete documentation
Access / Area Not Ready	23	18%	Work face not cleared, isolations not in place
QA / Inspection Not Ready	26	21%	Outstanding inspections, open punch items
Dependency Not Ready	14	11%	Preceding trades incomplete, missing energisation sequence
Ready to Start	40	32%	All prerequisites met;

Using the collaborative meeting to identify tasks to make ready was supported by digital dashboards that conveyed the current status of tasks. Dashboards clarified which tasks were missing from plans, which were planned but not ready, and which were genuinely ready to start.

In the execution week the tasks are further progressed from started to complete. The integration of digital planning, information management, and production control platforms enabled a comprehensive review of the entire production process, thereby supporting an efficient lean production system.

Enhanced readiness through integrated visual management

Rather than relying on percentage summaries alone, the visual environment made the readiness gap cognitively obvious: tasks lacking prerequisites were immediately distinguishable from those genuinely make-ready. This shifted conversations from reporting progress to diagnosing conditions. As teams could now see where dependencies and blockages accumulated, coordination efforts became more targeted and proactive.

Importantly, the combination of Power BI and VisiLean strengthened both the **quality** of tasks (clearer definitions, prerequisite compliance) and the **quantity** of realistic commitments (a greater proportion of tasks meeting readiness criteria). This improvement emerged not from additional reporting effort but from the clarity produced by shared, visualised information that

aligned teams around the same evidence. The visibility of the task status translated into improved PPC that resulted from the improved weekly work plan.

As shown in Figure 2, the use of visual management to develop digital dashboards supported the DLPS made visible the mismatch between tasks that were included in the weekly plan and those that were actually ready to start, supporting more reliable commitments and improved PPC.

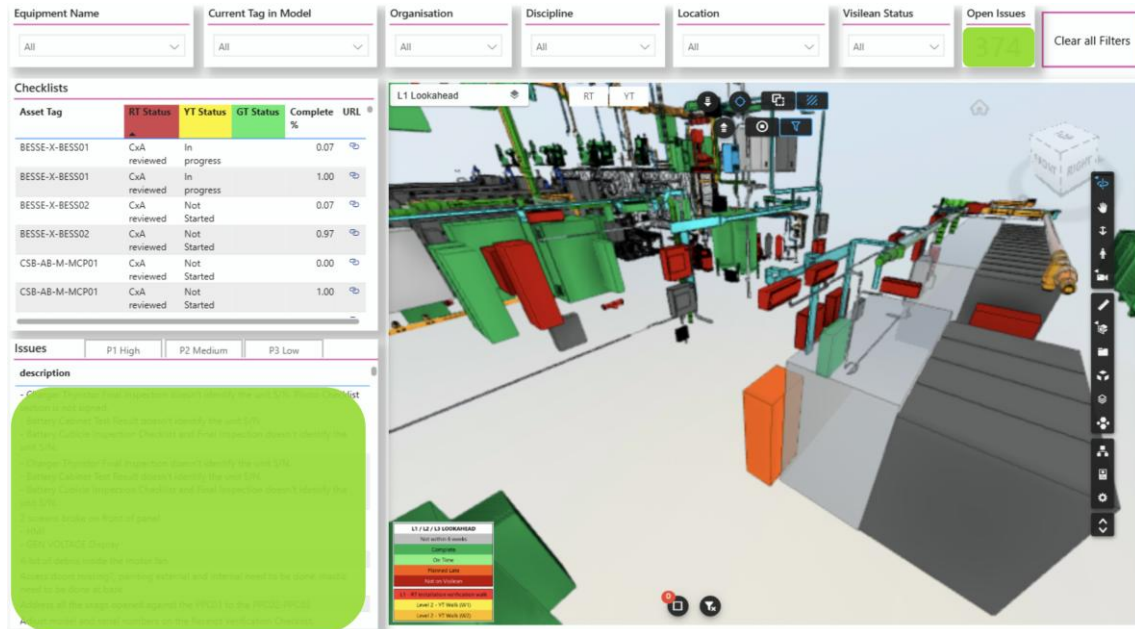


Figure 2: Comparing planned v ready

DISCUSSION

The findings illustrate how Lean principles can inform digital tool configuration during the transition from construction to commissioning. When configured to foreground readiness, platforms shaped how teams interpreted production status and engaged in planning. The shifts observed—broader participation, earlier constraint surfacing, and more realistic commitments—suggest movement from programme-driven reporting toward flow-oriented planning, indicating that digital tools can reinforce Lean behaviours when sociotechnical alignment is deliberate.

DLPS configuration was central. Dashboards, embedded prerequisite checks, and clearer task templates focused attention on conditions for reliable flow, functioning as cognitive scaffolds consistent with Flow logic in TFV theory (Koskela, 2000; Koskela & Ballard, 2003). As teams prioritised readiness over programme alignment, previously hidden constraints surfaced earlier, supporting more dependable commitment-making.

The intervention also indicates how digital artefacts can support psychological safety. Before DLPS deployment, discussions were dominated by a few individuals and constraints were handled informally. With dashboards as shared, depersonalised reference points, variance was treated as a system condition rather than individual failure, enabling more inclusive issue surfacing. This aligns with research that shows information framing shapes the interpersonal climate of planning conversations.

Commissioning amplified these effects. Readiness-gap analysis showed commissioning work lagged due to unresolved documentation, access, isolation, and inspection prerequisites—conditions poorly represented in programme-driven logic. Making these prerequisites explicit within the DLPS improved visibility and earlier coordination, supporting sociotechnical approaches that represent system readiness more faithfully than traditional planning.

Finally, iterative refinement of dashboards, templates, and routines underscores continuous learning in Lean practice. Small adjustments produced meaningful gains in planning reliability, reflected in rising PPC. The findings suggest Lean–digital integration is strengthened through feedback cycles and readiness-first configuration, not one-off tool introduction. The contribution is to show how readiness-first digital configuration can act as a sociotechnical trigger, shifting teams from programme-driven compliance toward flow-oriented Lean behaviours.

CONCLUSIONS

This study showed how digital tools can strengthen Last Planner System® behaviours when configured to foreground readiness and support collaborative planning during the transition from construction to commissioning. By embedding clearer task definitions, prerequisite checks, and readiness-first dashboards into the DLPS, planning conversations shifted from programme-driven reporting to diagnosing flow conditions. This contributed to improved planning reliability, reflected in the increase in PPC from approximately 12% to 64%.

A key contribution of the research is the identification of a significant commissioning readiness gap, much of which stemmed from documentation, access, isolation, and testing prerequisites that were not visible through traditional programme-driven approaches. Digital routines that made these conditions explicit enabled earlier coordination and more realistic commitment-making. The findings also highlight that behavioural improvements emerged not from digital tools alone, but from the alignment of tool configuration, facilitation practices, and leadership behaviours.

While based on a single case, the mechanisms identified—readiness visibility, clearer task definitions, depersonalised variance discussions, and iterative learning cycles—are likely transferable to other commissioning-heavy or interdependent project environments. The study provides practical insight into how sociotechnical alignment can support Lean–digital integration and improve planning reliability in complex project settings. Based on these findings, practical implications for configuring digital tools to support commissioning are outlined in the Recommendations section. While these mechanisms are likely relevant in other commissioning-heavy environments, further multi-case research is required before broader generalisation.

RECOMMENDATIONS

The findings suggest several practical steps for teams aiming to better integrate Lean principles and digital tools during commissioning. First, configure platforms to foreground readiness rather than programme adherence. Embedding prerequisite checks, clear task definitions, and consistent naming conventions enables teams to judge whether work is genuinely make-ready, shifting conversations from dates to conditions.

Second, use dashboards as shared diagnostic artefacts, not performance surveillance. Facilitated this way, they depersonalise variance, lower the risk of speaking up, and encourage earlier surfacing of “Not Ready” work—improving the reliability of commitments.

Third, structure weekly planning around disciplined make-ready routines, explicitly linking construction and commissioning workflows. Regular review cycles should surface constraints early, assign owners, and track removal so planning becomes proactive rather than reactive.

Fourth, reinforce Lean–digital alignment through leadership and facilitation. Non-punitive responses to readiness gaps and framing constraints as system signals reduce defensive reporting and sustain collaborative problem-solving.

Finally, introduce commissioning readiness logic earlier in the project. Represent documentation, isolations, QA inspections, and system interdependencies in digital task

structures from the outset to avoid late constraint discovery and improve predictability through the transition to commissioning.

REFERENCES

- Agrawal, A. K., Zou, Y., Chen, L., Abdelmegid, M. A., & González, V. A. (2024). Moving toward lean construction through automation of planning and control in the Last Planner System®: A systematic literature review. *Developments in the Built Environment*, 18, 100419. <https://doi.org/10.1016/j.dibe.2024.100419>
- Ballard, G. (2000). *The Last Planner System of production control* (Doctoral dissertation). University of Birmingham.
- Ballard, G., & Howell, G. (2003). Lean project management. *Building Research & Information*, 31(2), 119–133. <https://doi.org/10.1080/09613210301997>
- Ballard, G., & Tommelein, I. (2016). Current process benchmark for the Last Planner System®. *Lean Construction Journal*, 2016, 57–89.
- Ballard, G., & Tommelein, I. (2021). 2020 current process benchmark for the Last Planner System® of project planning and control. *Lean Construction Journal*. <https://doi.org/10.60164/47e7h7a1b>
- Calvetti, D., Magalhães, P. N. M., Suján, S. F., Gonçalves, M. C., & Campos de Sousa, H. J. (2020). Challenges of upgrading craft workforce into Construction 4.0: Framework and agreements. *Proceedings of the Institution of Civil Engineers – Management, Procurement and Law*, 173(4), 158–165. <https://doi.org/10.1680/jmapl.20.00004>
- Conte, M., Trentin, B., Pedó, B., Bernardo Martim Beck da Silva, E., & Navarrete, S. (2022). Exploring the use of digital visual management for Last Planner System® implementation. In *Proceedings of the 30th Annual Conference of the International Group for Lean Construction (IGLC30)* (pp. 645–656). <https://doi.org/10.24928/2022/0172>
- Daniel, E. I., & Pasquire, C. (2019). Creating social value within the delivery of construction projects: The role of lean approach. *Engineering, Construction and Architectural Management*, 26(6), 1105–1128. <https://doi.org/10.1108/ECAM-06-2017-0096>
- Daniel, E. I., Pasquire, C., Dickens, G., & Ballard, G. (2017). The relationship between the Last Planner System® and collaborative planning practice in UK construction. *Engineering, Construction and Architectural Management*, 24(3), 407–425. <https://doi.org/10.1108/ECAM-07-2015-0109>
- Dave, B., Kubler, S., Främling, K., & Koskela, L. (2016). Opportunities for enhanced lean construction management using Internet of Things standards. *Automation in Construction*, 61, 86–97. <https://doi.org/10.1016/j.autcon.2015.10.009>
- Dave, B., & Sacks, R. (2020). Production control systems for construction at the nexus of lean and BIM. In L. Koskela et al. (Eds.), *Lean construction: Core concepts and new frontiers* (pp. 54–84). Routledge.
- Duan, H., & Schwartz, T. (2021). Last Planner System® implementation using physical and digital visual management-based tools: A case study in Luxembourg. In *Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC29)* (pp. 65–74). <https://doi.org/10.24928/2021/0161>
- Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly*, 44(2), 350–383. <https://doi.org/10.2307/2666999>
- Fewings, P., & Henjewe, C. (2019). *Construction project management: An integrated approach* (3rd ed.). Routledge.
- Fernandes, L. L. A., Hastak, M., & Costa, D. B. (2024). Assessing social, technical, and operational maturity dimensions for digital transformation in the construction phase. In *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction (IGLC32)* (pp. 1232–1243). <https://doi.org/10.24928/2024/0214>

- Gamage, I., Malik, M., Andargoli, A., & Chavez-Clavijo, R. (2025). Theorizing lean as a sociotechnical system: Examining reciprocal interactions between lean social and technical subsystems. *Journal of Operations Management* (advance online publication).
- Görsch, C., Tezel, A., Lappalainen, E., Seppänen, O., & Koskela, L. (2026). Lean Construction 4.0: Enhancing situational awareness for autonomous decision-making through digital visual management. *Engineering, Construction and Architectural Management*, 33(2), 1070–1100. <https://doi.org/10.1108/ECAM-03-2025-0538>
- Hamzeh, F., González, V. A., Alarcón, L. F., & Khalife, S. (2021). Lean Construction 4.0: Exploring the challenges of development in the AEC industry. In *Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC)* (pp. 207–216).
- Howell, G., & Ballard, G. (1998). Implementing lean construction: Understanding and action. In *Proceedings of the 6th Annual Conference of the International Group for Lean Construction (IGLC)*. Guarujá, Brazil.
- Koskela, L. (2000). *An exploration towards a production theory and its application to construction*. VTT Technical Research Centre of Finland.
- Koskela, L., & Ballard, G. (2003). What should we require from a production system in construction? In *Proceedings of the 11th Annual Conference of the International Group for Lean Construction (IGLC)* (pp. 1–8). Blacksburg, VA.
- McHugh, K., Dave, B., Tezel, A., Koskela, L., & Patel, V. (2022). Towards lean construction site 4.0: Integrating lean and digital technologies. In *Lean Construction 4.0* (pp. 17–34). Routledge. <https://doi.org/10.1201/9781003150930-4>
- Moradi, S., & Sormunen, P. (2023). Implementing lean construction: A literature study of barriers, enablers, and implications. *Buildings*, 13(2), 556. <https://doi.org/10.3390/buildings13020556>
- Pikas, E., Pedó, B., Tezel, A., Koskela, L., & Veersoo, M. (2022). Digital Last Planner System® whiteboard for enabling remote collaborative design process planning and control. *Sustainability*, 14(19), 12030. <https://doi.org/10.3390/su141912030>
- Power, W., Sinnott, D., & Mullin, A. (2021). Improving commissioning and qualification delivery using Last Planner System®. *Lean Construction Journal*, 2021, 1–16.
- Tezel, A., & Aziz, Z. (2017). Visual management in highways construction and maintenance in England. *Engineering, Construction and Architectural Management*, 24(3), 486–513. <https://doi.org/10.1108/ECAM-02-2016-0052>
- Yiu, T. W., & Cheung, S. O. (2006). A catastrophe model of construction conflict behaviour. *Building and Environment*, 41(4), 438–447.