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Synthesizing Last Planner® System, Takt, and Scrum Theory and Practice to Enhance Construction Project Delivery

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Abstract

Question: How can Scrum assist Last Planner® System and Takt to address extant gaps in Lean Construction planning?

Purpose: This research paper evaluates how Scrum can assist Production Planning and Control and synthesizes Last Planner® System, Takt, and Scrum into an integrated Project Management Methodology. It examines whether it is best to use the methods in their 'purest' sense or if hybrid versions of each should be incorporated.

Research Method: To develop and implement this process the research uses mixed methods using case study design and data collected from observation, documentation review, measured impact, and semi-structured purposeful interviews.

Findings: The research developed and evaluated a novel theoretical-based production planning & control process. Last Planner® System, Takt, and Scrum theory address shortfalls in Critical Path Methodology and traditional construction management theory. Using the methods in their purest form complement one another with improved and more consistent Planned Percent Complete.

Limitations: The research is conducted on a single residential project.

Implications: Application of theoretical and practical benefits of LPS®, Takt, and Scrum can enhance construction delivery.

Value for authors: This paper highlights the impact from synthesizing different methods to address known gaps in current Last Planner® System and Lean Construction practice.

Keywords: Last Planner® System, Takt, Scrum, Lean Construction.

Paper type: Case study

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Introduction

Construction planning exists in an environment of poor productivity and studies have found that less than 60 percent of planned tasks are executed weekly (Ballard and Howell, 2004; Liu et al., 2010; Ballard and Tommelein, 2016). Leading Lean Construction (LC) researchers (Tommelein and Ballard, 2016; Daniel et al., 2020; Ballard, 2020) have suggested looking outside construction to other sectors, for example the software and IT sectors, for ideas to further improve construction's processes.

Last Planner System® (LPS®) is *the* key tool of LC but despite its lauded success, advances in literature and iterative research highlight shortcomings on reliance on LPS® as the sole production planning and control methodology of LC. Identified gaps include inadequate visualization capabilities (Aslam et al., 2020), an absence of proactive participation in management of construction delays, changes, and contracts (Olivieri et al., 2019), an incomplete constraints closeout process (Power et al., 2021), a desire for more explicit clarity on the roles of those managing frontline supervisors (Ballard and Tommelein, 2021), and the ineffective execution of root cause analysis and corrective actions (Aslam et al., 2020; Poudel et al., 2020). Another critical concern of sole reliance on LPS® is the 'picking and choosing' of individual functions as opposed to full implementation of the complete system (Daniel et al., 2015; Ebbs et al., 2018; Ballard and Tommelein, 2021; Power et al., 2022, 2023). Furthermore, Aslam et al. (2020) posits isolated implementation of LPS® functions further exposes its vulnerabilities.

Integration of different scheduling and planning methodologies seeks to address shortfalls in both traditional and innovative methods with the specific objective of increased planning reliability and construction productivity (Sheikhkhoshkar et al., 2022a). Recent years has seen a proliferation of combined or integrated methodologies: Seppänen et al. (2010) and Seppänen (2014) with a comparison of Takt Time and Location Based Management System (LBMS) Planning Methods; Emdanat et al. (2016) with Takt, LPS®, and labor tracking; Toledo et al. (2016) with Building Information Modelling (BIM) and LPS®; Olivieri et al. (2016) with LBMS, LPS®, and Critical Path Methodology (CPM); Sheikhkhoshkar et al. (2023b) examined the concept of functionality for integrating methods; and, Karaz and Texiera (2023) looked at LPS®, LBMS, and BIM combined.

Previous research has shown Takt combined with LPS® (Linnik et al., 2013; Frandson et al., 2014; Schöttle and Nesensohn, 2019) and found that Takt exercises simplified transparency of the workflow and promoted improved design of operations. Takt time is a Lean manufacturing concept where the objective is to ensure customer demand rate is achieved. It is the '…division of available work time per shift by the customer demand rate per shift' (Rother and Shook, 1998). In manufacturing this necessitates adjusting the production rates of different workstations to ensure that inventory does not accumulate and that workstations are not underutilized while waiting for work (Hopp and Spearman, 2011).

Case studies exist of Agile and Scrum enhancing design performance (Demir and Theis, 2016; Streule et al., 2016) but there is a paucity of examples showing Scrum assisting construction execution (Power et al., 2022). The Scrum Guide (Schwaber and Schwaber, 2020) describes Scrum as: '…a lightweight framework that helps people, teams, and organizations generate value through adaptive solutions for complex problems.' The 2020 Current Process Benchmark for LPS® (Ballard and Tommelein, 2021) has called for: '*A* *rigorous description and evaluation of these methods (Scrum and Kanban) should be done to decide if to incorporate into future LPS Benchmarks'*, (p.55). Despite advancements from recent studies there is still a research gap between the alignment of short-term, medium-term, and long-term planning (Emdanat and Azambuja, 2016; Tezel et al., 2020; Amer et al., 2021;). Additionally, PMBOK 7th edition has extensive focus on Agile Project Management, and this should also be a focus of LC as there is current gap in connecting Project Management to Production Planning and Control in both LC literature and practice.

The aim of this research is to evaluate how Scrum can assist Production Planning and Control and synthesizes LPS®, Takt, and Scrum into an integrated Project Management Methodology. The application of Takt and Scrum to complement LPS has shown tangible 'hard' and 'soft' benefits to the construction delivery process. Previous LC literature has shown that there is no single method that offers a 'complete' planning solution – all have gaps that require improvisation which leads to inconsistency of application.

Literature Review

Theoretical Underpinnings

LC developed as a set of countermeasures to specific problems in construction and in recent years has adopted and adapted the methods and principles of Lean production for application in construction management (Koskela et al., 2019). LC researchers and practitioners have constantly sought ideas and inspiration from both inside and outside of construction (Abdelhamid, 2004). Koskela (2000, 2017, 2020) repeatedly asserts that the traditional domain of management does not adequately address the theory of production – a shortfall addressed in manufacturing by Lean. Koskela also found that construction was primarily managed through decomposition of tasks and costs minimization which led to un-systemized management. Therefore, according to Koskela (2000, 2020), where traditional production theory is based on multiple transformations, Lean extends flow theory (time, information, materials) and value generation theory (information, customer viewpoint), and adds transformation theory where appropriate. The transformation theory of production is the view that a production system can be broken down into its elementary operations consisting of inputs and outputs (Koskela, 2000); these inputs are individually optimized to optimize the entire system. LC literature asserts reliance on transformation theory alone is found to be one of the major contributors to performance and productivity loss in construction (Sacks, 2016; Koskela, 2000, 2020).

Shingo (1989) asserted the flow theory of production differs radically from the transformation view, in that it identifies both process and operations in a production sequence. Using both processes and operations to describe a production system is helpful as firstly, identification of non-value adding activities is easier and, secondly, variation and lead times can be reduced creating smooth flow (Dahlberg and Drevland, 2021). Ballard (2000) asserts workflow is defined as '…the movement of information and materials through a network of production units, each of which processes them before releasing to those downstream.' However, Sacks (2016) suggests this concept is not directly applicable to construction in the same context as manufacturing as construction is a fixed product. Therefore, the flow metaphor in the LC literature could refer to the flow of 'work packages' - crew, product, work method, design information, and equipment (Sacks, 2016, p.646).

In his empirical work Koskela (2000) posits the value view of production as placing customers primarily in the focus because value can only be defined by the customer. This contrasts with mass production where the value is recognized with transformation of materials and inputs and does not meet the customer request. Value generation theory also promotes collaborating with suppliers to build in quality and acknowledge internal customers' needs when designing the production system (Liker, 1996). Scrum from the software sector has a distinct value focus. Its theory is founded on empiricism and Lean thinking (Sutherland and Sutherland, 2014, Engineer-Manriquez, 2021) and is built on three pillars of transparency, inspection, and adaptation. It emerged from complex adaptive systems theory and was heavily influenced by Lean thinking as it emerged from Japanese manufacturing (Sutherland and Schwaber (2007). Scrum has become the predominant planning methodology in software development, replacing Critical Path Methodology (CPM) in many cases, and has attracted attention from construction researchers (Engineer-Manriquez, 2021; Layton et al., 2023)

The theory of CPM and traditional waterfall models intends the initiation and direction of action before it takes place (Laufer and Tucker, 1987). However, in construction, practitioners used CPM for controlling operations as opposed to recurring planning, and focused more on who was responsible for deviations instead of improving the lookahead plan for near-term work execution (Laufer and Tucker, 1987; Koskela et al., 2014). Koskela (2000) suggested using Last Planner System® and the metric of Planned Percent Complete (PPC) to address the shortfalls in traditional construction management and CPM practice and theory. LPS® theory addresses this shortfall of CPM by avoiding variability and minimizing the negative impacts when variability occurs.

Last Planner® System

In the 2016 Benchmark Ballard and Tommelein (2016) proposed five key principles of LPS®:

1. All plans are forecasts, and all forecasts are wrong. Forecast error varies with forecast, length, and level of detail.
2. Planning is dynamic and does not end until the project is completed.
3. Involving those who will directly supervise or perform the work being planned results in better plans and greater ability to adapt plans when needed.
4. Actors within a project production system can make choices that help or hinder achieving project objectives, for example, actors have discretion.
5. Understanding project objectives and the current and future state of the project helps actors make better choices. In other words, for project team members to help, they must know what we are trying to do, the current state of the project, and potential future states.

LPS® was purposefully designed as a methodology for planning and controlling production on projects and in the 2020 Current Process Benchmark (Ballard and Tommelein, 2021), LPS® was extended to '…both production (i.e., striving for targets) and project planning and control (i.e., setting targets)'.

The core functions of LPS® are:

- master / milestone schedule,
- phase / pull planning, look ahead and make-ready process,
- commitment / weekly work planning,
- daily huddles / coordination and learning and action (Ballard, 2000; Daniel et al., 2015; Ebbs and Pasquire, 2019).

Takt Time Planning

Takt theory and concepts is a central principle of production system design; the Toyota Production System stated Takt was integral to its success (Haghsheno et al., 2016). Takt time seeks to align the production rates of trades by pacing work sequentially through planned zones creating continuous workflow, reliable handoffs, and an opportunity to continuously improve the production system (Frandson et al., 2013). In Takt time planning in construction, the work zones and pace can be adjusted as crews move through the zones at constant rates. Detailed design of production operations and zone demarcation based on work densities becomes a principal system design input (Frandson et al., 2015). Takt time planning aims to maintain resource use when possible, but also attempts to create the most optimal solution for the production system (Lehtovaara et al., 2020). The use of production science allows continuous flow to be established where possible and to manage buffers in the form of additional crew capacity (Frandson et al., 2014).

The concepts of Takt are critical to controlling construction flow and can tighten LPS® by introducing stricter discipline around task durations and repetition. Schöttle and Nesensohn (2019) looked at integrating Takt into LPS® and found that Takt brought advantage where repetition could be found but the flexibility of LPS® was critical for improvements and reaction to breakdowns. Takt and LPS® work together to generate and maintain flow and Frandson et al. (2014) found that the disciplined structure and alignment from the Takt plan improved the Last Planner's ability to plan their work successfully. Takt increases visualization of the planning process (Grönvall et al., 2021) and addresses the absence of visual management in LPS® as found by Aslam et al. (2020).

Agile & Scrum

The Scrum framework consists of Artifacts and Events. Artifacts represent work or value and include the Product Backlog (the prioritized list of work to be undertaken) and the Sprint Backlog (the set of Product Backlog items selected for the Sprint) (Engineer-Manriquez, 2021). Events include Sprints (where ideas are turned into work and are fixed length events usually of 1, 2, or 4 weeks duration); Sprint Planning (initiates the Sprint by ordering the work to be performed); the Daily Scrum (to inspect progress towards the goal of the sprint, a time-boxed 15 minute huddle); the Sprint Review (to inspect the outcome of the Sprint and discuss future changes required); and the Sprint Retrospective (to plan improvements to the process and implementation). Actions occur within each Sprint and progressively lead to delivery of accepted and validated value to the customer (Layton et al., 2023). Figure 1 presents the Artifacts and Events of the Scrum framework.

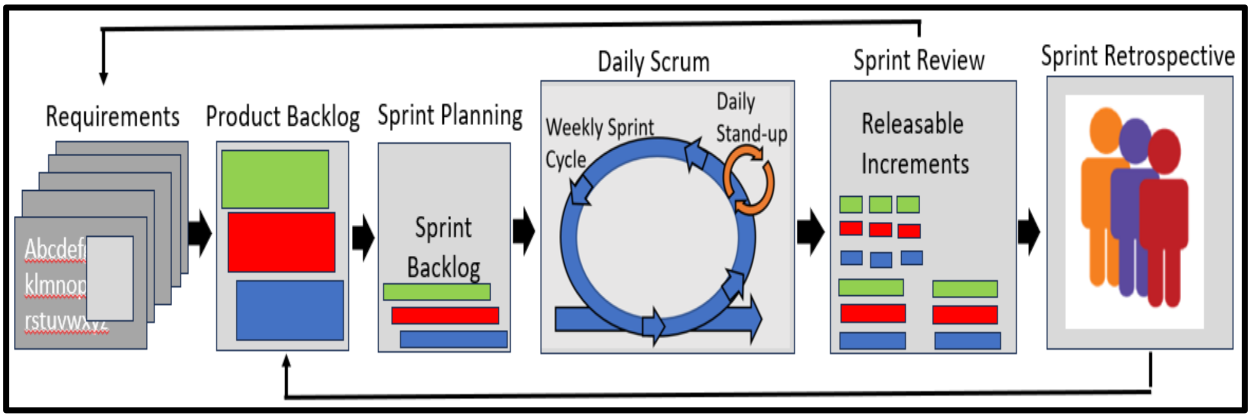

Figure 1 - Artifacts and Events of the Scrum framework.

Scrum has the potential to address some of the LPS® 'blind spots', like proposing a constraints management process (Engineer-Manriquez, 2021; Power et al., 2023), introduction of Scrum roles (Poudel et al., 2020; Engineer-Manriquez, 2021; Power et al., 2024) and implementing a focused performance analysis process (Layton et al., 2023).

Distinct role definitions like Product Owner (PO), Scrum Master (SM), and Developers bring clarity to the Scrum process. The PO is a directing role that looks after the business side of the product or service, is accountable for effective Product Backlog management, and prioritizes the work for the next Sprints. The SM is an enabling role that creates the environment for success, primarily by helping remove constraints and keeping the Developers shielded from external distraction and focused on the goal of the Sprint. The Developers in Scrum are those responsible for creating and developing the product and the value. Scrum teams are deliberately small (no more than 8 developers) and ideally possess cross-functional skills, so they retain control of how they progress their work (Poudel et al., 2020; Engineer-Manriquez, 2021; Layton et al., 2020, 2023).

The empirical exposure model of Scrum allows teams make decisions that are based on real observations, feedback, and results as opposed to simulations based on research or a mathematical formula. Work is decomposed into actionable portions, observing results every step of the way. This allows teams to rapidly respond and adjust to stay on track (Layton et al., 2023, p.7). Software and IT have successfully adopted Agile to improve its focus and processes. Unlike the traditional methodologies, Agile methods deal with unpredictability and change by primarily using people's creativity rather than relying on cumbersome and wasteful processes (Layton et al., 2020).

Combining of Different Methods

Recent years has seen focused research at combining different methods to enhance construction planning and complement traditional practices. Tillman and Sargent (2016) examined a combination of BIM and LPS® in a case study and found BIM improved visualization and assisted Last Planners to better understand the lookahead process while improving the quality of work assignments. The BIM model relevance was also improved by earlier constraints identification through LPS®. A planning model that integrated LBMS, LPS®, and CPM was proposed by Olivieri et al. (2016) through case study research. A key finding was the increased focus on production control as opposed to the traditional project control. It also introduced concepts of task measurement, buffers, constraints analysis, subcontractor involvement in planning, workflow lookaheads, and performance management. A reliability assessment methodology examining BIM and integrating LPS®, a linear scheduling method, and critical chain project management to develop tracking and control procedures for modular construction projects was proposed by Salama et al. (2021). Concepts of Takt time and Just in Time were introduced and the system offered a systematic procedure for forecasting look-ahead schedules using a correction factor. Interventions by the project team in LPS® sessions was shown to improve schedule alignment.

A total of 26 integrated scheduling methods and 44 scheduling methods' functionalities were identified by Sheikhkhoshkar et al. (2023b). The study concluded that understanding the functionality of integrated methods in the construction industry is necessary for selecting the most appropriate planning and scheduling approach based on the required project's goals and objectives. A finding was that integrated scheduling methods should pay more attention to a recognized shortcoming of LPS® - the non-performance of root cause analysis and corrective analysis. Despite numerous efforts at combining different methods there is a paucity of practical research exhibiting how Scrum can assist Production Planning and Control in construction.

Theoretical Synthesis

Takt requires LPS® principles and theory to support its planning, execution, and control functions (Frandson et al., 2013; Schöttle and Nesensohn., 2019). Takt extends LPS® to create continuous flow, to assist resource utilization, increase visualization, and to seek out repetitiveness (Frandson et al., 2014). Both LPS® and Takt require Scrum theory support in conceptualizing the goal and roadmap (Layton et al., 2023), in implementing a robust constraints and inputs management process (Power et al., 2022), and adding stricter definition to construction roles (Poudel et al., 2020; Layton et al., 2023; Power et al., 2024). Table 1 summarizes the key elements of the theoretical findings.

As Scrum is a non-specific framework, it in turn requires the structured construction-sector-developed LPS® principles to address the nuances and peculiarities of construction (Poudel et al., 2020). Both LPS® and Scrum are pull systems designed to limit work in progress to allow increments of work to flow to the customer (Engineer-Manriquez, 2021). Takt theory supports Scrum by scientifically dictating the pace of the schedule and offering specific target dates for constraint resolution. Additionally, using Agile to set the Product Goal, Product Roadmap, and Release Planning establishes the lookahead process and challenges and enhances the CPM logic from the outset (Layton et al., 2023). CPM fulfils its own function in determining the project duration, identifying timing of key milestones, and to serve as a status reporting tool (Laufer and Tucker, 1987).

Summary of Literature Review

Reliance on 'hard' methods alone cannot accommodate variability and foster the deep collaboration required for progressive and adaptive planning below the subcontract level (Daniel et al., 2020; Koskela, 2020). A clear gap exists in current planning practices where the collaborative lookahead involving the subcontractors is absent. There isn't any performance measurement and no clear process for surfacing constraints and managing them towards resolution. LC brings distinct improvements to traditional practices but there are still areas for enhancing LC's contribution. Numerous studies have presented the need to combine different methods to offer greater value. This research examines the introduction of Scrum practices to complement LPS® and Takt with a view to creating a more holistic and robust Production Planning and Control process. According to Koskela and Howell (2003) and Daniel et al. (2020), LPS® and Scrum methods integrate Transformation, Flow, Value theory and promote the necessary collaboration to allow both ‘hard’ and ‘soft’ approaches to planning. Takt promotes continuous flow by setting the schedule pace. In isolation, LPS®, Takt, and Scrum each have their ‘blind spots.’

Table 1 - Synthesized theoretical elements required for construction delivery.

Method	Key theoretical elements
Critical Path Methodology / Traditional construction management	Forms a network of linked activities that portrays the overall project scope. Intends the initiation and direction of action before it takes place. Uses mathematical modelling and quantitative models. Does not address operations production or incorporate the view below subcontract level. Uses suppositions and assumptions in forecasting.
Lean Construction theory - Transformation, Flow, & Value	Seeks smooth flow with minimum variation and addresses waste reduction. Transforms inputs to outputs; strives for continuous flow to improve output rate of the system; and, adds value in the form of quality and internal and external customer’s needs.
Last Planner System®	Looks for reduction of variability by: Constraint-free tasks, process performance measurement (PPC), examining reasons for task non-completion, creation of an available backlog, using make-ready and lookahead planning. Needs better constraints closeout direction, role clarification above Last Planner level, increased visualization, and more engagement in construction delays, changes, and contracts. Takt enhances planning and control of repetitive tasks.
Takt Planning	Satisfying customer demand rate. Maintain resource use while adjusting zone size and pace of crews. Uses production science to establish continuous flow. Takt is fragile, is easily disrupted by variation, and can be assisted with LPS® managing non-repetitive elements.
Scrum	Empiricism and Lean thinking founded on transparency, inspection, and adaptation. Observing and experiencing actual results and status. Accepting change and making change readily. Accommodates planning, execution, and control theory. Scrum concepts can address gaps in LPS® and Takt.

Literature posits that, theoretically, they can work well together and complement each other in a combined process. Therefore, it is important to conduct independent research to validate their concepts in practice and to offer a more robust delivery practice.

Research Design

The project

The case project is a residential complex within a development that has been under construction for 18 months. The overall project comprises 730 residential units, consisting of five apartment blocks (Blocks 1-5) ranging from 1 to 9 storeys and two duplex blocks. The development also includes a retail unit, creche, three amenity spaces, and public communal open spaces. This research focuses on three blocks, six storeys high, with 12 apartments per floor giving a total of 216 units to be handed over as a single phase.

Figure 2 – Case project with residential blocks under construction

Methodology

A mixed methods approach is adopted utilizing case study design and data collected from a literature review, observation, documentation review, and semi-structured purposeful interviews. As both quantitative and qualitative models have individual weaknesses, diligently utilizing mixed methods assists minimizing bias by compensating for shortfalls in some methods with the comparative strengths of the other methods (Creswell, 2013). This enhances the validity and reliability of the collected data and strengthens causal inferences by enabling observation of data convergence or divergence (Abowitz and Toole, 2010; Leicht et al., 2010).

The research utilized case study design at a single project. Yin (1993) states that when a researcher is investigating into the 'how and why' of a set of events, a case study offers distinct advantages not found in more quantitative research tools. Principles of action research and learning were also applied allowing interventions and augmentations to be implemented. The research included embedment of a 'Lean facilitator' to the project team and attended site on one to two days per week over a 6-month duration. The 'Lean facilitator' also worked on other projects with the same company so essentially became a member of the company. This classified the researcher as being an 'insider' – a privileged position according to Byrne et al. (2015) as the researcher is a member of the community being studied. Despite early grounded theorists viewing participants' words and actions merely as data (Glaser and Strauss, 2017), Charmaz (2014) argues the researchers position affects their role with participants and their actions.

A sequential explanatory approach (Creswell, 2009) was used, with the quantitative data (PPC and RNC) being collected weekly as the project proceeded and the qualitative data being gathered after project completion. Figure 3 presents the sequential research design.

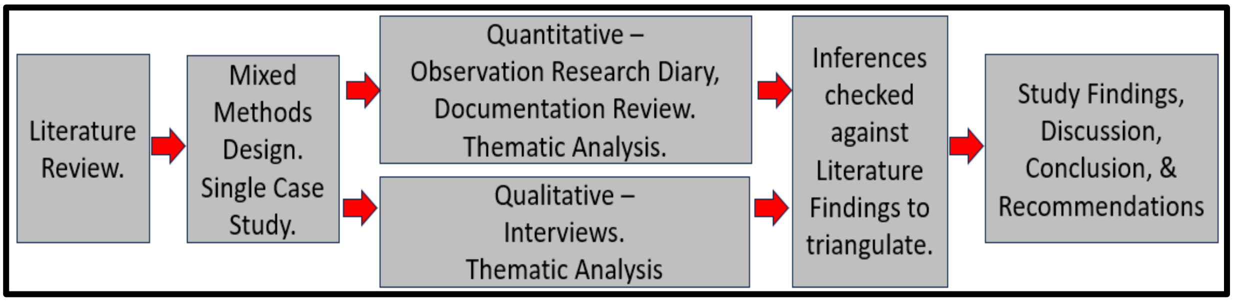

Figure 3 – Sequential Research Design.

The purposes of the literature review were to examine the theoretical and practical advantages and gaps of LPS®, Takt, and Scrum as well as assessing what research exists around previous integration of construction planning methodologies. The documentation review allowed data collection relating to site records. The purpose of the face-to-face interviews was to prompt two-way discussion between the researcher and the interviewee, as well as allowing behaviors, attitudes, gestures, and facial expressions be observed and picked-up, enriching the interview experience (Easterby-Smith et al., 2015).

The Lean Facilitator maintained an 'observation research diary' during the 6-month project duration. This involved recording behaviors, attitudes, moods, and observations from morning huddles, planning workshops, meetings, walks, reviews, and problem-solving sessions relating to the process implementation. Yin (1993) and Mason (2002) posit researchers should go to the natural settings where activities occur and observe what people 'really' do in those settings. Mason (2002, p.87) adds if one is '… intending to enter a setting or situation to carry out some form of observation, then you will need to prepare yourself not just for the process and technique of observance, but also for social interaction'. According to Leicht et al. (2010) observational studies are particularly useful in construction research as construction has so many social interactions; researching how teams work and interact offers understanding into how people lead and make decisions. During time with the team the researcher recorded any notable observation, and a daily report was committed to the 'observation research diary'. This allowed thematic analysis of the diary records in accordance with Creswell (2009). Comprehensive documentation data was available, comprising schedule and budget reports, revisions of P6 schedules, Product Goal and Road Map visuals, pull plans, contract documents, weekly LPS PPC reports, marked up weekly work plans, reasons for non-completion (RNC), Scrum burndown charts, Trello boards data, constraints logs, and the lessons learned log. By relying on several independent sources of evidence, the researchers were able to increase the construct reliability of the research (Yin, 1993).

The qualitative element of the study consisted of semi-structured interviews with a chosen purposeful sample of key project participants who were familiar with the weekly planning process on the case site. Interviews can become sites for the construction of knowledge (Charmaz, 2014), with the researcher and participants producing knowledge together. The constructed knowledge can reveal depth, feeling, and reflexive thought (Aburn et al., 2023). Unique sources were purposely sought to increase validity and to provide a wider research perspective, as advocated by Yin (2009) and Stake (1995). The initial interviewee panel were mature construction professionals at supervisor to management level within their organizations. In total, this group had 16 members and provided the panel from which to select the interviewees. Some members were staff with the same subcontractors and executed similar roles. Deselection of duplicated roles left nine potential interviewees. According to Guest et al. (2006), data saturation refers to a point in the research process when no new information is discovered from data, and redundancy of the same findings begins and continues in the data analysis process. The researchers were satisfied that saturation was achieved after analysis of seven interviews and the remaining two interviewees were not required.

Participant anonymity was ensured by not recording any person's name or identifying the main contractor, subcontractor, or project name. Each participant was assigned an alphabet identifier – A through to G and their role in the project is stated. Table 2 presents the interviewees categorization.

Table 2 – Categorization of Interviewees

Respondent	Years in Construction	Category
A	33	Client Project Manager
B	28	Main Contractor Project Director
C	22	Main Contractor Project Manager
D	31	Mechanical Supervisor
E	12	Electrical Supervisor
F	16	Plaster Boarding Supervisor
G	23	Groundworks Supervisor

The interviews were transcribed and analyzed using a thematic analysis approach, as suggested by Braun and Clarke (2006). Emerging data was organized into different themes (Braun and Clarke 2006); inferences drawn from the emerging themes were checked by triangulation against the literature review findings and against other sources to check their reliability and integrity.

Limitations exist around the single case example and limited sample size.

Findings

Using Scrum to manage constraints

One of the key differences to the standard way of planning was the concepts of Scrum were used to manage to flow of inputs to create 'ready' tasks for the weekly work plans. Incomplete inputs are the single biggest cause of variation in construction and adversely affects PPC and weekly production. Previous experience of LPS® and Takt on the project highlighted the importance of a distinct focus on managing a robust constraints identification and resolution process. A key finding was the need to 'scan' the lookaheads at various levels of detail to ensure the constraints identification process was picking up as many issues as early as possible. This is using the Lookahead Planning function of LPS® to surface constraints to feed into the Scrum framework for resolution.

Allied to this was the need for continuous lookahead planning – no day passed without a formal lookahead with supervisors and contractors. This constant unearthing of detail was required to keep surfacing constraints and any issues that might inhibit or interrupt smooth work execution. Once a process for exposing constraints was in place it was then important to be able to order, prioritize, begin closing them, and offer the information back for checking to those who requested it. All constraints raised came to the Scrum Master who decided what was needed by when and who was best placed to resolve the issues. Using several Trello boards the Scrum Master held twice-weekly constraint sessions with the Developers to move at speed through the constraint's lists. New priorities were emerging as existing constraints sometimes grew into bigger deliverables. The key point was the resilience and persistence required to stick with the process.

Sprint Planning

The Release Planning, LPS® Pull Planning, and Takt Plans were aligned in looking ahead at least six months into the Milestone Schedule. To prepare for the highest effectiveness in execution it was necessary to ensure an excellent constraints identification and resolution process was in place. With constraints being raised daily these needed to be prioritized in Sprint Planning. The concept was to agree a finite volume of tasks to be worked on and released within each weekly sprint to allow stability in design resources allocated and to level the demand. Only one sprint at a time was planned with the objective of progressing towards constraint free tasks for at least two weekly work plans.

Sprint

Each constraint was allocated an estimation of effort required to get it resolved. Over time, the estimation process became more accurate and dependable, and the Development team grew in confidence regarding its constraint resolution capabilities. Each constraint had an effort value ranging from 1 to 8 story points. Any story greater than 8 points needed to be broken down into further detail and split in two or more tasks. Figure 4 presents the Sprint story point closeout and the rate of constraint closure per sprint per week.

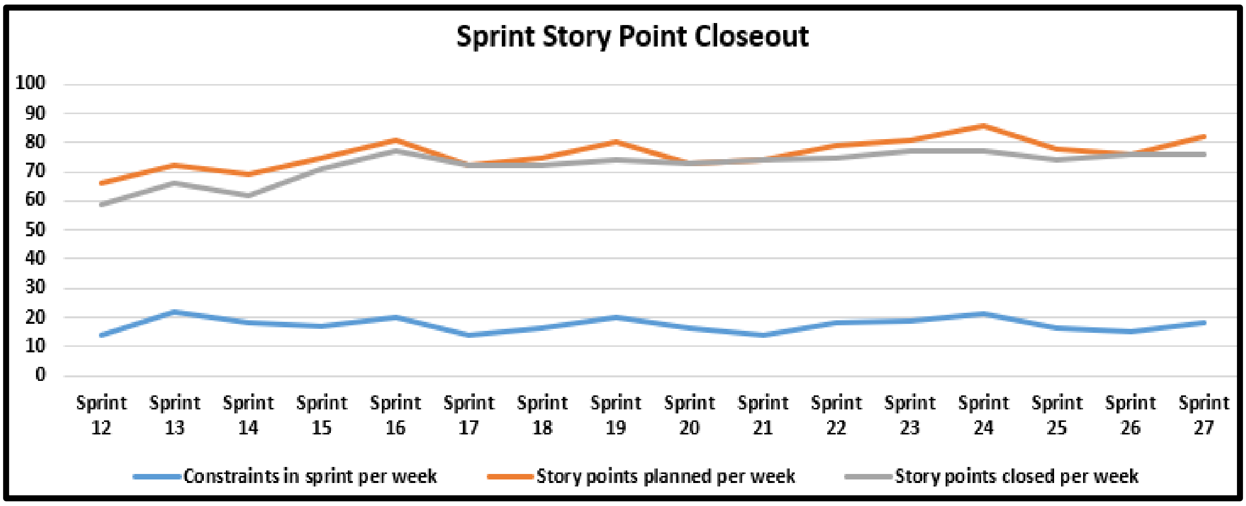

Figure 4 - Constraint closure burndown

The critical outcome was the ability to balance the workload on those closing the constraints while also ensuring weekly consistency in burndown. Additionally, a process now existed that surfaced constraints as far as possible in advance, which worked reliably weekly to remove constraints, and then provided constraint free tasks for crews to commit to weekly work plans.

Sprint Review

As part of the weekly calendar the SM ensured each sprint was closed and reviewed before a new sprint commenced. This entailed offering each closed constraint to the raising party to ensure it has brought the intended value. Unresolved constraints were prioritized in the next weeks sprint. Figure 5 offered data for the sprint review which presented the constraint removal performance.

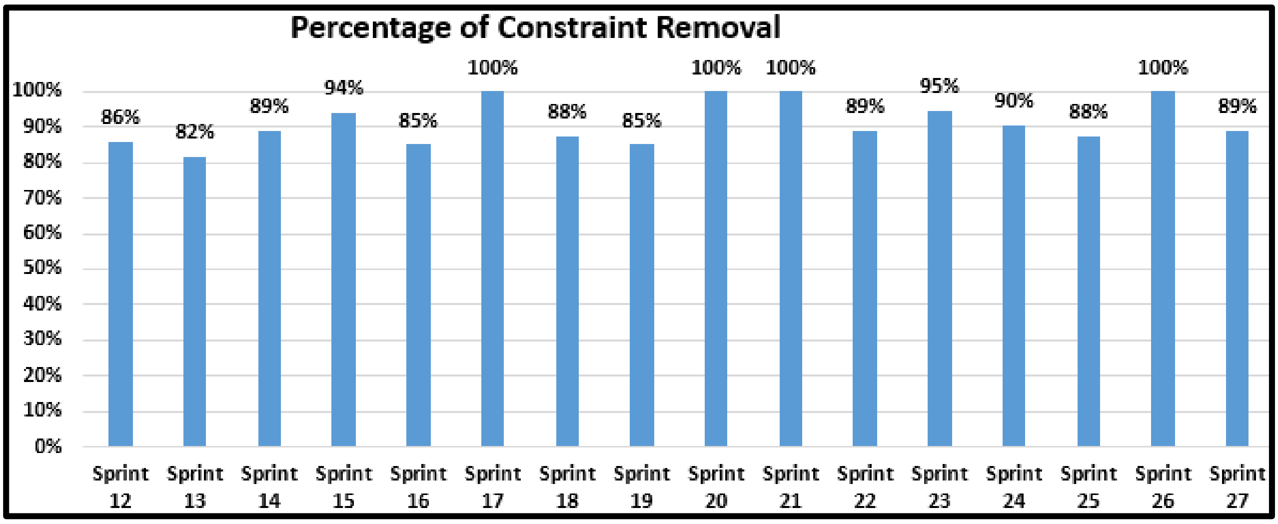

Figure 5 - % of Constraint Removal

Sprint Retrospective

The process was reviewed monthly to ensure the customers were receiving value. Data was available in the form of burndown charts and Task Made Ready metrics. However, feedback from those originally raising the constraints was a critical indicator of success or the need for further refinement. Again, this was a critical aspect of improving the process and the addition of this retrospective session enhanced the overall Lookahead Planning and Commitment Planning aspects of LPS®.

Task Made Ready (TMR) metrics

Lookahead planning focuses on making tasks ready in the sequence and necessary speed to allow work to be executed to maintain the project on schedule and achieve reliability of construction workflow. The team sought to avoid just-in-time resolution of constraints and aimed to have all constraints resolved at least two weeks in advance of the weekly work plan commitment date. Figure 6 presents the success of working to make tasks ready and the importance of setting a closeout target of at least two weeks in advance of commitment to a weekly work plan.

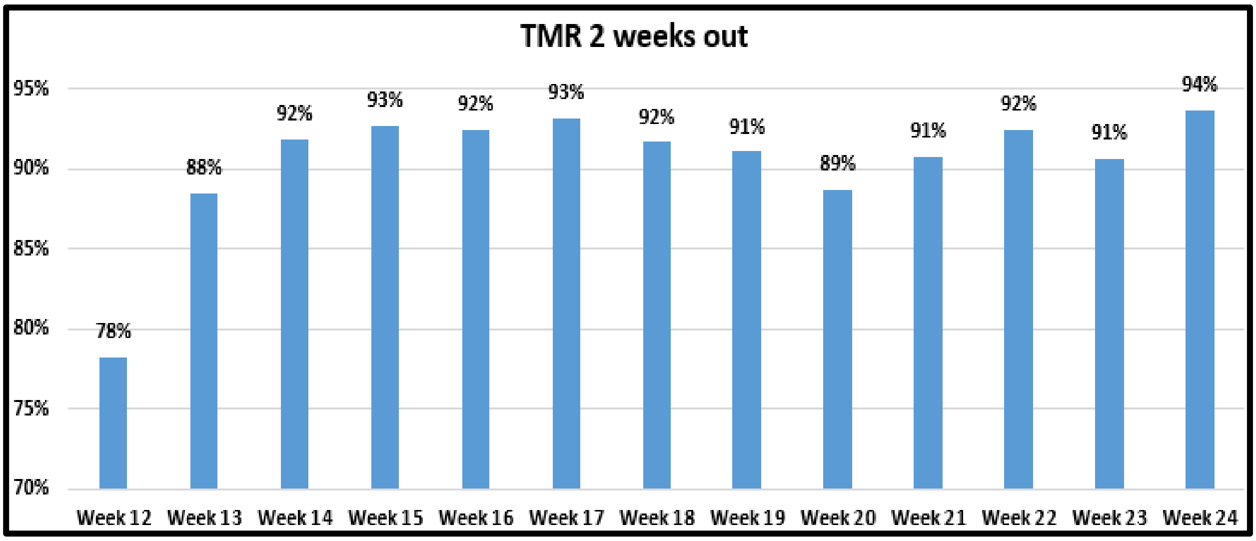

Figure 6 - TMR measured two weeks in advance of commitment plan.

Successful constraint burndown and a high percentage of constraint removal does not necessarily result in a high number of TMR. Therefore, it is important that the final preparation of tasks follows right up to the point of work execution. This diligence is especially critical to ensuring space becomes available at the right time as seeking Takt time of a single day needs precise management to avoid pileups and disruption.

Synthesis of theories

Analysis of the literature confirms a clear gap in the ability of both CPM and traditional construction management theory to underpin the complete execution of construction projects. The embedded researcher proposed, and the team agreed, to trial a combination of Agile, Scrum, LPS®, and Takt planning for the production planning and control of the case project. Each method had been used across the company's projects over the previous year so knowledge was available to show what advantages each method could offer. In this proposed process, LPS® and Takt are both executed as designed. Table 3 presents how the process was implemented and describes it, its steps, the functions, where the methods should be used, who is responsible, and the objectives of each step. The 'undertakings' column in table 3 are the key functions in Agile, Scrum, Takt, and LPS® that have emerged from the literature review.

The key findings from table 3 are the ordering of the functions and where and when they interact with one another; who is responsible; and what is the key objective of each undertaking or function. This process allows the true theoretical and practical potential of both methods to be fully exploited. Agile and Scrum fill in gaps and complement both methods, permitting the functions of LPS®, Takt, and Scrum to be used as originally conceived and subsequently adapted for construction. The addition of Scrum and Agile sets up the Product Goal and establishes the Product Roadmap - both offer clarity and starting points for the LPS® and Takt planning sessions. Scrum specifically manages the inputs, and this closes a practice gap as there is an absence of specific direction in literature as to how constraints resolution is to be addressed. Literature strongly advises LPS® and Takt adhere to their core principles and functions, and both perform at their best when this environment is created. The proposed process and Scrum's function in the Product Goal and Roadmap clarification, key individual's role definition, inputs management, and learning and improvement facilitates such an environment where LPS® and Takt have the greatest opportunity to function as designed.

Table 3 – Production Planning & Control Process

Step	Function	Method & Frequency	Responsible	Objective
1	Agree & assign roles & responsibilities.	Scrum. (Once).	Product Owner	To bring clarity & definition to individual's roles & responsibilities.
2	Develop Product Goal, Product Roadmap, and Release Planning. Incorporate CPM milestones.	Agile & Scrum. LPS® & CPM. (Once).	Product Owner	Define the purpose of the project; expose the key features required; agree high-level timing.
3	Overall Process Analysis & Pull Plan. Takt analysis & Takt planning.	LPS® & Takt. (Once per 3 months or as needed).	Product Owner	Agree sequence & identify what is repeatable; identify production outputs required; balance crew sizes to achieve outputs; zone demarcation; target to completion dates while including buffer. Involves trades in operations design.
4	Lookahead planning, Process Planning, Constraints identification.	LPS® & Takt. (Weekly).	Scrum Master	Trade involvement in task breakdown, work structuring, handoffs, decoupling buffers, resource loading, first-run studies, procurement plan updates, logistics planning, visual representation. Flow walks.
5	Inputs management & constraints closure.	Scrum. (Daily).	Scrum Master	Creation of a backlog of constraint-free activities. Communications process for prompt addressing & closure of constraints. Using metrics like Task Made Ready.
6	Weekly work plans - construction; Sprints - inputs & constraints management.	LPS®, Takt, & Scrum. (Daily & Weekly).	Scrum Master	Committing 'made ready' tasks to work plan. Adhering to or resetting Takt plan. Utilising buffers. Sprint planning & reviews of inputs management.
7	Daily huddles & Scrum standups.	LPS®, Takt, & Scrum. (Daily).	Scrum Master	Daily touchpoint or reset, plus check if support is required. Are we 'releasing' handoffs?
8	Learning & continuous improvement.	CPM, LPS®, Takt, & Scrum. (Weekly).	Scrum Master	Learning from Planned Percent Complete, Reasons for Non-completion, and Burndown data. Implementing improvements and feedback to schedulers / CPM owners.
9	Monthly process retrospective.	Scrum. (Monthly).	Product Owner	Check on the process - what is working, not working, and needs adjustment? Are metrics and data relevant? Are we on track to achieve our Product Goal?

In Table 3 the key Scrum features are defining the roles and responsibilities, setting the Product Goal and Product Roadmap (in conjunction with CPM, LPS®, and Takt), conceptualizing what the end-product and pathway to completion might look like, managing all inputs to the production system through sprint planning and sprints, learning and continuous improvement, and checking and adjusting the process with a monthly retrospective. Using this process ensured greater clarity and discipline relating to team members roles and the importance of the integration of the functions of the various methods.

Planning

The team used an Agile methodology for initial planning. The Roadmap to Value as shown in Figure 7 was followed and the team developed the Product Goal, the Product Roadmap (Figure 8), and a high-level Release Plan. Firstly, the Product Owner identified the Product Goal. The Product Goal was:

> *To achieve Client Ready to Snag milestone for Blocks A, B, and C by November 10th, 2023. This achieves our company's annual completions target for this project.*

The agreement of, and commitment to this milestone, was a critical starting point on the project as there was no ambiguity of purpose in what was to be achieved.

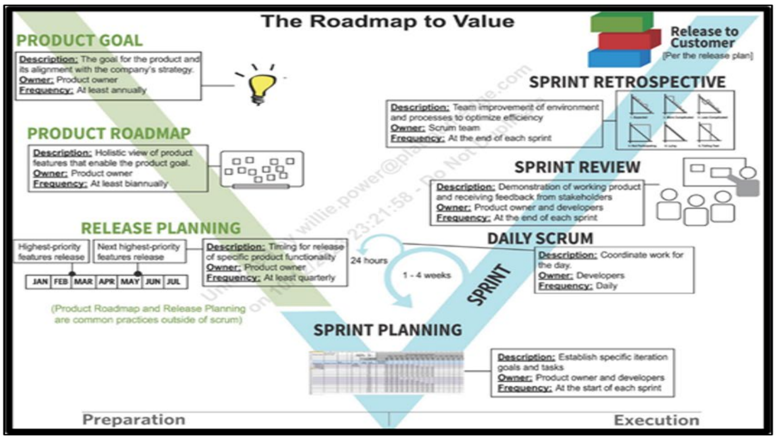

Figure 7 – Roadmap to Value (Layton et al. 2020)

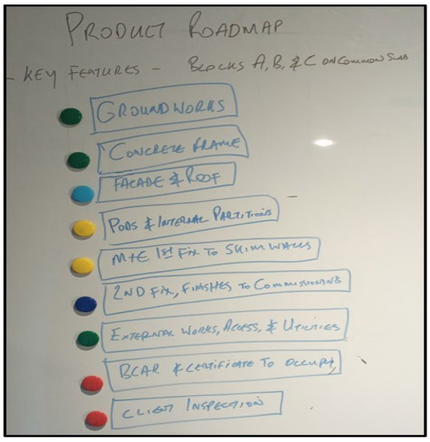

Figure 8 – Product Roadmap

The Product Roadmap exercise delves deeper into the scope than a CPM schedule and critically involves a broader involvement from the delivery team and selected key trade contractors. This was to seek a better understanding of repetition and replicability in the build sequence as well as probing to see what phases of the project could commence in parallel or run overlapping with the other blocks. In Agile and Scrum, release planning is somewhat comparable to Pull Planning however, the team continued the planning and execution with LPS® and Takt functions. The key feature Agile brought is the number of preliminary exercises that took place to best determine the execution strategy for the work phases. This conceptualization is an important feature in Product Development and including it as an exercise in construction planning is a positive addition. While the CPM owned the key milestones, aligning with Agile theory through an iterative progression towards executing individual phases of the Product Roadmap introduced LPS® and Takt exercises.

Figure 9 shows examples of Operations Process Analysis, sequencing and balancing, work structuring exercises, pod delivery and install optimization, and zone sizing and balancing trials. All of these contributed to building out the Pull Plans and Takt plans in relevant detail and accuracy. A key feature of the planning process was the requirement to work in lookahead windows that were sized appropriate to the roles within the team. The PO held full ownership therefore needed to have full project-duration visibility. This meant long lead items like bathroom pods and basement, or roof mounted mechanical and electrical plant and cabinets procurement were the responsibility of the PO. The SMs area of vision primarily went to 3-month Phase Pull Plans with occasional 6-month lookaheads with the PO. Every month the Pull Plans were refreshed, and the schedule horizon was scanned out to 6 months to ensure no long-lead item of equipment, material, or specialist installer was overlooked.

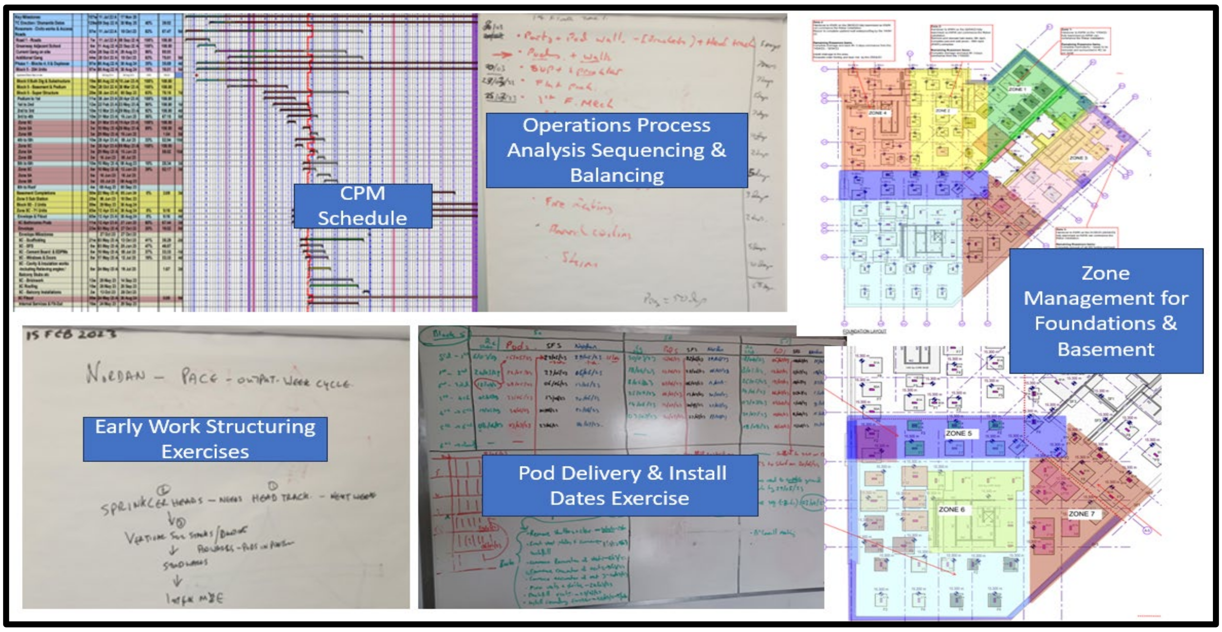

Figure 9 - Exercises to apply detail to Pull Plans and Takt planning.

The Developers attended the Pull Plan sessions and had input and oversight into what needed to happen over the next three months. However, the Developers primary focus became the 6-week lookaheads and the importance of ensuring each task was ‘made ready’ prior to the week it was needed to be executed and included in the weekly work plans.

Everything that could be planned and executed through a Takt plan was committed to that plan. If an activity had an issue or if there was an element of work that sat outside Takt, that was delivered through LPS®. The weekly work plan became a commitment list of those activities on the Takt plan and those coming through LPS®. Figure 10 presents examples of the iterations from sticky note to excel-based pull plans and the generation of Takt plans that were both posted on the site floors and on the Big Room screen and walls.

Controlling and monitoring occurred daily and weekly. At the daily production huddles the Weekly Work Plan was updated. Any task that could disrupt the flow of the Takt plan was taken to the ‘parking-lot’ and was addressed after the huddle. The critical target was keeping the Takt plan on-track every week while always showcasing to the contractors that continuity of workflow was visible four to six weeks and further out ahead. The key to retaining resources was plan visibility into the future allied to evidence that the plan was effective weekly.

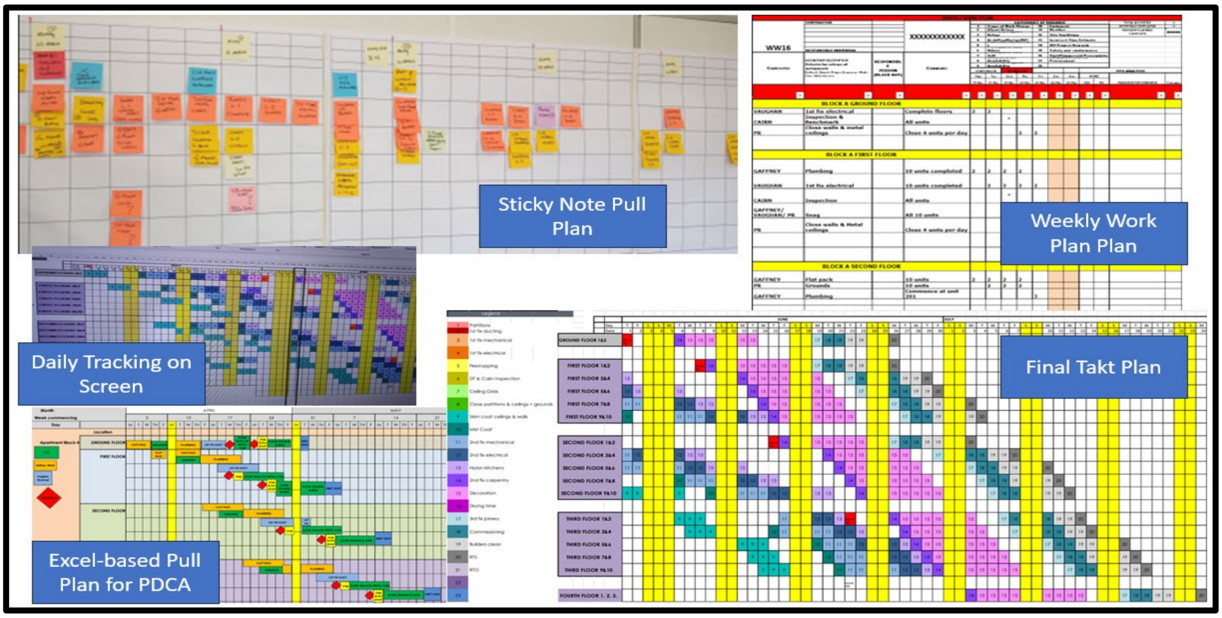

Figure 10 - Pull Plans, Weekly Work Plan, Takt Plan.

Impact on PPC

Planned Percent Complete was used on the project as a metric to measure the effectiveness of the planning and lookahead process. By correlation, this was also a measure of productivity and a verification of schedule adherence. Figure 11 presents the PPC over 40 weeks of the implementation with Takt and Scrum introduced.

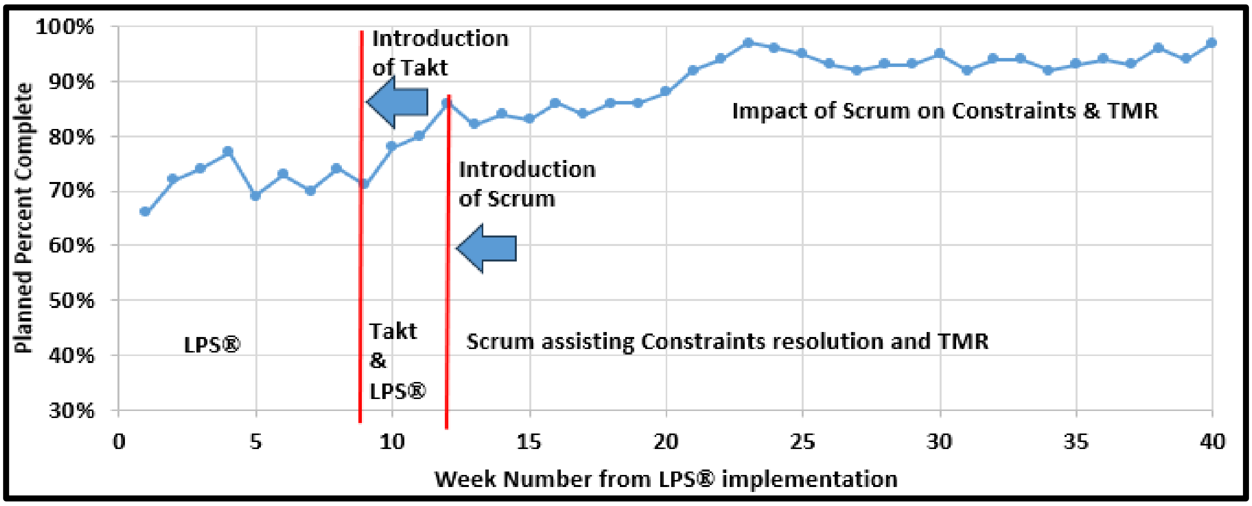

Figure 11 - Project PPC with LPS®, Takt, and Scrum.

The first 9 weeks of the implementation focused on LPS® alone and averaged 72% PPC. Takt planning was then introduced and by week 18 PPC had improved to 83%. Scrum was introduced to assist the constraints process at week 12 and results became evident by week 12. Over the next 6 weeks PPC rose above 90% and stabilized at 93% until the end of the research at week 40. This is a key finding and points to the importance of the diligence required to ensure an effective constraints identification and resolution process. This in turn offered value in the form of stabilized inputs, increased TMR, and resulting improved commitment planning with higher PPC.

The overall 21 percent increase in average PPC is a critical finding, as Lean construction researchers highlight the positive correlation between PPC and productivity. Liu et al. (2010, p.240) established '…PPC and Productivity are positively correlated. As the PPC value increases, productivity increases as well.' The 11 percent PPC increase over the final 22 weeks (application of Scrum to the constraints process) of the 40-week implementation confirms increased productivity and directly accrues from a more diligent and focused constraints identification and resolution process.

Shared schedule ownership

The novel approach to planning with increased visualization, trade involvement, design team involvement, and continuous iterative examination of work structuring brought both soft and hard results to the project and the team. Increasing PPC is a critical performance metric for continuous improvement as it has also been shown that many construction projects struggle to achieve more that 60% PPC when using traditional methodologies. Projects are originally costed and scheduled assuming 100% of tasks are executed as planned and the difference between planned and actual is a deficit causing the site management team to spend much of their time improvising to keep on track with the CPM schedule (Ballard, 2020).

Accompanying the 'hard' PPC metrics was a meaningful change in attitudes and behavior towards the planning process. In traditional practice, ownership of the schedule was inconsistent; did the scheduler 'own' the schedule or did the PM own the schedule? The introduction of a clear process led to all interested parties 'co-owning' the schedule. Accruing from the trade's involvement in the Pull Planning, Process Analysis exercises, Lookahead Planning, Flow Walks, constraints exposure, Commitment Planning, Daily Huddles, and improvement projects, a change in attitude and behavior towards the entire planning process was evident. Once the routine was embedded the trades were enthusiastic about the collaborative planning sessions and after several 'uncomfortable' moments for some contractors, when the consequence of missing commitments exposed the impact on other contractors and PPC, better alignment of purpose and intent was achieved. A culture change was evident where it was no longer a combative trade versus management team environment but transitioned more towards a single team wanting to progress towards milestones together. Interviewee C noted *"…trades began to converse more openly about coordinating entry to work zones as no one wanted to keep other trades persons idle or delayed"*.

Obvious benefits for the trades were better lookahead reliability helping work force stability, materials deliveries, timely design information, and having safe space available to move into. Issues and problems did not disappear but the approach to how problems were resolved changed. Trade supervisors became more proactive in looking ahead and conversing with other supervisors as the visual Takt plan prompted an urgency to adhere to the daily and weekly commitments. The Takt plans and weekly work plans for each block were posted in a room on the ground floor of each block making them easily accessible to all trades. It was common to see several supervisors at the planning wall conversing and coordinating amongst themselves. Outside the core functions of Scrum there were behavioral changes that influenced the functioning of LPS® and Takt also.

Interview Findings.

Implementing new methodologies involves change and, by nature, humans will always have inhibitions towards the unknowns surrounding change. The case project had utilized LPS® for over 18 months and in this time had adopted LPS®, Takt and then Scrum to complement the traditional planning methodologies. A critical finding has been that learning new methodologies takes time, and they need to be implemented over a reasonable duration to allow team members and contractors adapt into new routines. A summary of the key interview findings is presented in Table 4.

Table 4 - Summary of interview findings

Theme	Findings
Clarity of purpose	Using the Product Goal and Product Roadmap initiated exercises that focused thinking and planning on the project's purpose and key features. This alignment carried into the detailed planning sessions, assisted work package structuring, and facilitated early engagement of specialist suppliers and contractors.
Planning process	Awareness of the functions within LPS®, Takt, and Scrum permitted a stable production process that involved all parties at distinct levels of planning depending on their requirements.
Roles & Responsibilities	Greater clarity around the roles, responsibilities, and accountabilities of the team members and necessary interactions with designers and specialists.
Inclusion of design team	Aside from existing design workshops, there was a distinct focus on addressing design related constraints in a manner that eliminated wasteful interactions. A clearly defined issue could be resolved promptly.
Preparation for work	The introduction of a formal process and routine for surfacing constraints, resolving them, and having ready-made tasks prepared in advance of commitment planning reduced wasted effort and 'making-do' during work execution.
Better productivity	Introducing LPS®, followed by Takt, and utilizing Scrum to assist Lookahead Planning and Make Ready contributed to higher and more dependable PPC with resulting greater and consistent productivity.
Continuous improvement	The rigor and discipline within the Scrum framework ensured greater focus on improving the process by aligning weekly sprint reviews and PPC and reasons for non-completions outcomes. Monthly retrospectives offered an opportunity to review the overall planning process.

The interviewee findings were broadly supportive of the advantages accruing from the process. As the selected interviewees covered a deep cross-section of the project delivery team it was interesting to note how the supervisors learned more about the purposes of the project while the client project manager became much more aware of the challenges and successes occurring in the field execution.

Interviewee A stated: "I now understand how a late change in a client's requirement can impact those who are delivering the work and how disruptive delays can be to the production plan". Interviewee G noted: "Eventually, senior management began to realize the challenges we must surmount regarding securing extra labor or materials in reaction to a late change order. They then tried to ensure as much as possible was 'frozen' as early as was feasible. This was good for us". Despite the successes noted in table 4, there were constant challenges along the way and having an Agile mindset alongside a structured problem-solving approach was necessary to address possible disruptions.

Challenges encountered

It wasn't always easy to achieve alignment between management and contractor's supervisors regarding the lookahead. As the 'heated' local construction economy is working with limited resource supply it was sometimes difficult to get contractors onboard with increasing resource to satisfy demand. While Takt lookaheads offered greater visualization of the lookahead the reality of resourcing the demand was a challenge. Some contractors sought excuses and reasons not to bring extra resources and when under pressure went as far as denying they had agreed to achieving some commitments. When senior directors of the subcontractors were invited to attend any Pull Planning or weekly coordination sessions there was a noticeable positive and proactive change in behavior towards collaborative planning.

The existing practice of allowing a contractor a full floorplate of 10 apartments (large batch) to be working on was challenged by initially seeking a five-apartment handoff and then looking for a two-apartment handoff. This was strongly resisted by some contractors as they had subcontracted the entire floorplate out to individual subcontractors. The subcontractor had their own approach of having workers in multiple apartments simultaneously as opposed to zonal and sequential progression. This was resolved by spending time with the contractor and coaching them through how working in smaller batches with more frequent handoffs moved them faster through the floor, limited their work in progress, and allowed them claim for payment for completed apartments earlier.

Some of the improvements emanating from the learnings from PPC and RNC required changes to the financial arrangements between contractors and subcontractors. This issue wasn't immediately resolvable, and the planning process had to accommodate the nuances around subcontractor's pricing and payment arrangements.

Discussion

The synthesized Production Planning & Control process

The synthesized Production Planning & Control process was generated through literature analysis and practical research. Understanding and interpreting the theoretical underpinnings of each method helps their integration into the process and over time, the team members realize the 'why' and 'how' specific features of each method contribute to the overall process. Using the most specific method wherever possible is beneficial as it puts the delivery system under strain, and this highlights bottlenecks and areas for process improvement. As Takt is the most precise but also most fragile method it is recommended to apply Takt as early as possible in the planning process. This approach aligns with Tommelein (2017) and Linnik et al. (2013) who sought to use Takt to 'shape' batches and schedules of work. Seeking repetition in construction processes and assembling the trade crews into the Takt trains is a visual practice that assists the team understand the detailed interactions, handovers, and inputs required for smooth-flowing delivery. Interviewee C noted: *"Having the trades understand the sequence and knowing the importance of vacating a zone on the agreed evening was a big step forward in better site organization and structure"*.

LPS® is more robust and accommodating of change than Takt and becomes an enabler for the execution of Takt as noted by Schöttle and Nesensohn (2019). LPS® principles like '…plan in greater detail as the start date for planned tasks approaches,' when understood by the team, posit why it is necessary to focus on the detail of ensuring all necessary inputs are in place and having sufficient time available to allow any constraints to be resolved. Scrum is the least precise method and is sufficiently flexible and agile to hold and manage all inputs to the project delivery process. A key principle in the Agile Manifesto is the preference of 'Individuals and interactions over processes and tools,' and this is explicitly visible in the collaborative planning required in Takt, LPS®, and in the Scrum methodology. A critical question raised was whether 'hybridization' should occur or if each method should function in its 'purest' form?

Implementing the methods in their 'purest' forms is a key outcome of this research. While Takt is relatively new to construction there is sufficient academic and practitioner research to justify its application, without compromise, to the project planning process. There are similarities between Takt and LPS®; both positively complement one another and both research and practice point to this positive correlation. LPS® has developed since the early 1990's and through annual research publications (IGLC and Lean Construction Journal), updating of Benchmarks (2016 and 2020), and its widespread use amongst practitioners globally, it has continuously improved while also largely adhering to its original principles. Consequently, there is little need to tamper or modify LPS® in the proposed process. There is also little to be gained from any hybridization of Takt and LPS® as they naturally merge through the planning process with common Pull Planning, and both end up on a single weekly work plan and learning cycle.

Impact of Scrum

Scrum addressed a gap in LPS® and Takt, as both do not prescribe a closeout mechanism for constraints other than recording them and committing them to a log. The 2020 Benchmark suggest constraints be closed out as a team; while detail on the 'how' is lacking, this can be addressed with Scrum. In using Scrum in its 'purest' sense we must consider a resolved constraint as a 'complete' input that allows a task to be committed to a weekly work plan as the 'releasable increment' outcome from the Scrum process. As in 'pure' Scrum, the 'releasable increment' can be demonstrated to the end user as the completed constraint or input and must be accepted as 'done' by the party making the commitment to the weekly work plan. Constraints identification and early closure is critical as one of the principal areas for failure of LPS® and Takt plans is a delay to a necessary input for task execution.

'Making-do' and improvisation breaks the Takt process causing disruption, resetting of the trains, and using up buffer allocations. While the same impact on LPS® introduces postponement of tasks until all inputs are in place, there is a consequential impact on flow and on schedule dates. Much research exists on solutions to this issue, primarily focusing on identifying constraints as early as possible in the planning and lookahead process and utilizing metrics like Tasks Anticipated and Tasks Made Ready to ensure sufficient 'complete' and 'ready' tasks for commitment to the weekly work plans. This case project used the Scrum framework as a method for managing all these inputs. This has been successful, but it must be highlighted that vigorous and diligent examination of every task and activity must be undertaken to ensure the constraints are identified early. Scrum principles like prioritizing the highest value items, releasing value early and often, and ordering and sizing of User Stories assists both site teams awaiting complete inputs and those resolving constraints who can set and balance their workloads, thus avoiding peaks and troughs. This where the flexibility of Scrum brings the greatest benefit and value-add to the Takt and LPS® planning processes. The case project utilized Sprint Planning, Sprints, Daily Scrum Huddles, Sprint Reviews, and Sprint Retrospectives meaning all Scrum events were implemented fully. Additionally, it is essential that a trained and competent Scrum Master is available to the team to train, mentor, and coach the team on effective implementation of the methodology.

The introduction of Scrum roles brought clarity to the construction management team's duties and responsibilities. Duplication and crossover of communication and meeting attendance was reduced, and the focus facilitated more intense engagements. The critical role was that of the Scrum Master (SM) who attended the Pull Plan and Lookahead planning sessions with the specific objective of extracting as many constraints as possible from the attendees. The SM prioritized and ordered the constraints in the sprint backlog and at the next sprint planning meeting any urgent or incomplete constraints were sized by the Developers (design team members, trade contractors, suppliers, client representative, main contractor staff) and were accepted into the relevant sprint. The SM conducted a twice-weekly huddle to monitor and control constraint resolution. Completed constraints were brought to the attention of who raised them to ensure the query raised was adequately resolved. The key point in the constraints process was the ownership by the SM. Interviewee F noted *"…it was great knowing if you raised an issue that might delay your progress that you had confidence someone was going to assist you. Previously nothing happened until you raised the issue several times"*. Traditionally, both Takt and LPS® have had a shortfall relating to ownership and accountability for effective and diligent constraints management. The introduction of the SM illustrates the importance of this Scrum role complementing the planning process.

Improved and more consistent PPC

Percent Plan Complete (PPC) is used to measure the reliability of workflow and previous studies (Liu and Ballard, 2008; Liu et al., 2010) found a correlation between PPC and higher productivity. Liu and Ballard (2008, p.664) found the key was '…to focus on maintaining a predictable workflow and thus be able to match the available workload with capacity (work hours)'. Combining the different methods on this study directly contributed to improved and more consistent PPC. Findings showed Takt combined with LPS® led to an 11% PPC increase over LPS® alone. This is attributed to the increased diligence in planning and visualization introduced by the Takt application. The introduction of Scrum also had a major impact on PPC and led to a further 10% increase in PPC. The specific focus on constraints identification and resolution resulted in more consistent TMR and more reliable workflow. Acknowledging that PPC is not a specific productivity metric, nonetheless, this research confirms that Takt and Scrum enhances LPS® performance and offers practitioners a tested Production Planning and Control process that integrates all three methods while retaining each in their purest form.

Conclusion and Recommendations

This study has shown that LPS®, Takt, and Scrum can be combined, and their theoretical and practical concepts highlights opportunities to improve both LPS® and LC implementation. Higher and more consistent PPC accrued from diligent Takt planning and a focused constraint management process introduced by Scrum. Clearer Scrum role definition offers opportunity for construction management teams to reassess their team structure and to establish clearer lines of communication.

Future studies should examine further refinement of Scrum application to construction's processes and specifically utilize productivity metrics to measure improvement. Research should evaluate the potential for a Hybrid Agile-Lean methodology to further enhance existing Production Planning and Control implementation.

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