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Proposed Framework for Integration of LPS and LBMS in the Construction Projects

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Abstract

Question: How can construction project planning and monitoring be enhanced by the successful collaboration of the Last Planner System® (LPS®) and Location-Based Management System (LBMS)?

Purpose: The goal of this research is to create a realistic and understandable workflow that combines LBMS with LPS, allowing for better planning transparency and more efficient project monitoring by utilizing organized templates.

Research Method: The foundation of the research includes a review of previous studies on the integration of LPS and LBMS as well as an examination of planning processes, including master scheduling, phase scheduling, look-ahead planning, and weekly planning.

Findings: The study shows that while LPS offers clarity in rolling out milestones into manageable tasks and carrying them out within specified time constraints, LBMS is helpful for milestone planning and master scheduling. For integration to be successful, a structured workflow connecting master scheduling, phase planning, look-ahead planning, and weekly planning is necessary. Useful insights are produced by a monitoring system that integrates information from the planning and execution teams as well as other relevant stakeholders.

Limitations: The suggested framework, which is conceptual and template-based, has not yet undergone thorough empirical testing on a variety of project types.

Implications: Failure to adopt the LPS & LBMS framework may perpetuate shortcomings in existing planning methods, ultimately resulting in project delays.

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Value for authors: The present research improves project monitoring effectiveness and simplifies the integration of LPS and LBMS by providing researchers and practitioners with a helpful collection of templates and a straightforward process.

Keywords: Last Planner System (LPS), Location-Based Management System (LBMS), Integration of LPS-LBMS, Bottleneck Identification, 5-WHY Analysis, Fishbone Diagram.

Paper type: Full Paper

Introduction

The concept that Lean Construction (LC) is just a set of tools for removing waste is a fundamental misconception. It must be seen as an integrated socio-technical, production-control, and learning system intended to provide value through dependable workflow and respect for people, as outlined by the foundational LCJ and IGLC literature (Mossman, 2018; Abdelhamid et al., 2008). The method is based on the actual fact that weekly assignment failure—the ongoing ability of work teams to finish their committed plans—is the main cause of failure in the construction industry (Ballard, 2000). Therefore, the foundation of LC is a simple critique of the over-reliance on transformation-only production theory (the "T" in the Transformation-Flow-Value model) in traditional project management, which emphasizes the conversion of inputs into outputs at the expense of flow management and the definition of value from the viewpoint of the customer (Howell, 1999; Abdelhamid, 2004). These twin criticisms—of unreliable workflow and insufficient production theory—form the crucial basis for any realistic characterization of the field, as the Lean Construction Journal Editors' Note (2022) continues to argue. Pasquire and Connolly (2002) explore how moving construction processes into a controlled factory environment dramatically reduces waste and improves overall project efficiency. Sarhan et al. (2017) define Lean Construction as a production-based management approach grounded in the Transformation–Flow–Value (TFV) theory, focusing on waste reduction, reliable workflow, and value creation for clients. Trachilis and Thompson (2022) presented it as a practical leadership framework emphasizing collaboration, pull planning, continuous improvement, and tools such as the Last Planner System to enhance project reliability. Together, these works frame Lean Construction as both a theoretical model and an implementation-oriented management system.

Thus, the Last Planner System's commitment-based planning, shielding, and learning cycles act as an example of the production-control system at the core of Lean Construction, which regulates flow and ensures workflow reliability (Ballard, 2000). According to Abdulhamid et al. (2008) and Umstot (2017), this technical system is inseparable from its social component; it is socio-technical, requiring and developing respect among individuals through collaboration, made-ready processes, and the negotiation of reliable commitments. Finally, it is a learning mechanism to maintain progress. Building a culture of continuous adaptation involves more than just tools; it also calls for the scientific thinking and coaching practices of improvement kata, as outlined by Rother (2009) and highlighted in LC contexts by Tapase (2019).

To integrate the Last Planner System (LPS) and Location-Based Management System (LBMS), the basics of the tools needed to be understood. LPS is a lean tool that requires commitment from relevant stakeholders, collaboration during the planning phase, day-to- day monitoring, and implementation of collective resolution plans. Thus, in LPS, coordination amongst key stakeholders is important to achieve desired outcomes. In LBMS, on the other hand, the continuity of activities is optimized, and future performance can be forecasted principally based on the rate of production.

Therefore, to combine LBMS and LPS (Seppänen, Ballard and Pesonen, 2010), we need to have a framework established where data derived from one tool can be used in another tool for better understanding and visibility. Additionally, to address the shortfalls in performance or in case of deviations in other lean tools, e.g. 5 Why analysis and Fishbone diagram, are also part of the framework as tools for root cause analysis.

This research has been conducted in the project Azim Premji University, Bhopal, India which is being constructed by Shapoorji Pallonji E&C division. This is a newly started project where foundation construction activities were going on during the study. To ascertain the functionality of the framework, activity data have been used from the project.

The foundation of the Academic block of the project, Wing A, is divided into two locations, viz. Pour # 01 and Pour # 02. The scope of the study was restricted to excavation to backfilling works at the plinth level where the LBMS has been used to visualize activity flow concerning the Master Construction Schedule (MCS) and manpower mobilization planning. The inputs from LBMS have been used in LPS to prepare look-ahead plans and Fortnightly schedules for both pours. While preparing the LPS- Fortnightly Schedule, inputs have been taken from the execution team through Site Coordination Meetings and relevant stakeholders as a measure of collaboration. The execution teams were provided with Fortnightly Schedules for acquiring the required data from activities performed daily. Execution data were analyzed, and actual data were entered into LBMS templates at regular intervals. The constraints were captured, and corrective measures were communicated using a Responsibility Matrix through a template after conducting a thorough root cause analysis. Thus, the templates used for LBMS, LPS, Root Cause Analysis, and Responsibility Matrix formed a framework where communicating, capturing, analyzing data and corrective action become more effective.

Literature Review

In the evolving landscape of the Construction industry, a relentless pursuit of waste elimination has become its driving force. This effort extends far beyond merely reducing materials; it involves meticulously trimming down inventory, slashing cycle times, and driving costs down to deliver high-quality goods and services in the most efficient, effective, and responsive manner possible (Orr, 2005). Lean Construction is a transformative management philosophy that is reshaping the AEC landscape. Lean Construction is not merely a buzzword; it represents a movement with initiatives focused on minimizing waste, improving project performance, and ultimately enhancing customer satisfaction. Salem (2005) emphasized Lean Construction's remarkable capacity to significantly reduce waste, if not eliminate it.

At the core of this philosophy lies the synergistic integration of the Location-Based Management System (LBMS) with the Last Planner System (LPS) for construction project planning and control. Kenley and Seppänen (2009) highlighted how this powerful combination can enhance workflow reliability, reduce variability, and boost project performance, drawing from insightful case studies. Ajay Kumar Agrawal (2024) investigated the potential benefits of automation of planning and control in LPS to achieve Lean Concrete (LC) principles on construction projects through better implementation of LPS. Moreover, Seppänen and Ballard (2010) discussed the critical role of LBMS and LPS in providing real-time monitoring and control in construction projects. These systems offer real-time data on project progress, identify deviations from plans, and enable proactive decision-making, ensuring projects stay on track. Kenley and Seppänen (2010) further explored the theoretical and practical benefits of this integration, showcasing how it improves the accuracy and reliability of project schedules. LBMS and LPS were found to be complementary. (Seppänen, Olli; Ballard, Glenn; Pesonen, Sakari, 2010) LPS focuses more on the social process of planning and commitment, and LBMS is mainly a technical system using structured information to improve the quality of plans in the planning phase and to calculate progress metrics, forecasts and early warnings during the controlling phase. However, implementing these systems together is not without its challenges. Ballard and Howell (2004) identified barriers such as cultural resistance, lack of understanding, and technological issues, offering solutions and strategies to overcome these obstacles based on empirical evidence. Jan Emblemsvåg (2024) shows that the planning and execution using LPP through successive iterations of PDCA improves performance. This is a step forward because planning has become a living process and not merely steps leading up to a static plan that is outdated quickly.

Sacks et al. (2010) explored how integrating LBMS and LPS supports lean construction principles by enhancing flow, reducing waste, and increasing value. Whereas Aziz and Hafez (2013) pointed out that applying Lean Construction to the AEC industry is not a one-size-fits-all approach. The unique challenges of the construction environment demand flexibility, adaptability, and a strong emphasis on fostering collaboration among stakeholders.

It's often believed that Lean Construction is simply a collection of waste-reduction techniques. This approach lacks its actual nature and is an abstraction. Fundamentally, lean construction should be viewed as a system of integrated socio-technical, production-control, and learning. Its main goals are to create a dependable workflow, provide the customer with the most value possible, and foster a culture of respect for individuals and ongoing progress. To fully appreciate its transformational power in the construction industry, this reframing is essential.

This viewpoint is based on two fundamental criticisms, which the Lean Construction Journal Editors' Note (2022) reiterates:

1. The Weekly Assignment Failure: It is acknowledged that crews' incapacity to consistently finish their weekly work plans is the primary failure in the construction industry. This makes it very clear that strong production control is required to manage the flow of work, not merely the transformation of materials.
2. The Critique of Transformation-Flow-Value (TFV) Production Theory: The current project management theory, which placed an excessive emphasis on the "Transformation" of inputs into outputs (tasks and activities), was criticized in the beginning by Lean Construction. It made the case that overseeing the "Flow" of the job and making sure that the client sees "Value" are just as important, if not more so. Workflow variability and waste result from a transformation-only system that optimizes portions at the expense of the whole.

We have to engage a broader spectrum of thought in order to go beyond waste elimination. Abdelhamid (2004) expands on this by defining Lean Construction as a project delivery methodology with a general philosophy focused on respect for people and continuous improvement. This is simplified into the Lean Construction paradigm by

Hamzeh (2011), who identifies its key features as an emphasis on value creation and flow via collaborative planning and process consistency. Mossman (2018) positions Lean as a new management paradigm, suggesting that it is about producing value rather than just decreasing costs.

This paradigm's role as a production-control system forms its operational basis. In order to regulate production and ensure workflow reliability, Tommelein (2015) clearly characterizes Lean Construction as a socio-technical system that combines technical approaches (pull planning, Last Planner System) with social processes (team participation, commitment). Drevland et al. (2018) further this by putting forth a workable paradigm in which respect for people, production control, and ongoing learning are all interconnected and inseparable elements. This is not just a theoretical exercise; González et al. (2010) demonstrated that putting in place a system like this, customized for local conditions, directly enhances project delivery through improved pull and flow methods.

In the end, this system's ability to function as a learning system determines its sustainability. Rother's (2009) research on the Toyota Kata is crucial in this respect. By exposing the scientific problem-solving techniques and coaching cycles that are the foundation of true lean thinking, it breaks down the "waste removal" image. From an LCJ standpoint, Tapase (2019) emphasizes that Kata is the learning engine that integrates behaviors improvement, guiding teams to think scientifically about problems rather to just utilizing technologies. The socio-technical system may adapt and flourish because of this continual learning loop: plan, do, check, act, and instruct.

In general, Lean Construction is best described as a common triad: a Production-Control System that guarantees dependable workflow and provides value to customers; a Socio-Technical System that values people and encourages teamwork; and a Learning System that applies scientific thinking for continuing adaptation and development. This integrated perspective offers a significantly more potent and precise basis for understanding and implementing Lean in construction. It developed as an assessment of weekly failures and incomplete production theory.

Some researchers also focused on integrating Fishbone diagrams with the Last Planner System (LPS) to enhance quality management in construction projects. Gajare and Smita Patil (2016) discussed how Fishbone diagrams can systematically identify potential causes of quality issues, which can then be addressed through the collaborative planning and control mechanisms of LPS. Furthermore, the review examines the effectiveness of Fishbone diagrams and LPS in risk management, as highlighted by Hamzeh et al. (2012). They emphasized the strength of Fishbone diagrams in visualizing risk factors and their causes, while LPS plays a crucial role in mitigating these risks through improved planning and communication.

Additionally, Sacks et al. (2010) explore how integrating Fishbone diagrams with LPS supports lean construction principles. This combined approach helps in identifying and eliminating waste, improving workflow reliability, and enhancing overall project efficiency. The collaborative problem-solving potential of using Fishbone diagrams with LPS is further highlighted by Hamzeh et al. (2012), demonstrating how these tools can foster a collaborative environment in construction projects. Together, these reviews illustrate the synergistic benefits of using Fishbone diagrams and LPS to improve various aspects of construction project management, from quality and risk management to lean construction practices.

Lagos et al. (2024) propose a predictive model based on Last Planner System (LPS) metrics, applying the Design Science approach. Using 1,464 data points from 164 projects, the model accurately forecasts schedule outcomes (MAE 1.24%, $R^2 = 0.96$). The results show its potential as an early warning tool within LPS support software.

Research Methodology

The research begins with the need for a sequenced information flow where the process of construction activity planning shall enable dividing a project into some definite locations, resource balancing amongst them, optimizing and adjusting schedules, monitoring their implementation, and finally adopting an improvement plan. The study needed to develop a mechanism where information from various stages of the construction workflows can be efficiently analyzed to achieve a fruitful outcome. The research methodology shows how the conceptualization and implementation of the framework took place. The entire framework thus has the following four major parts,

- Planning phase: activity planning using LBMS and LPS,
- Execution phase: update the LP template with the required data
- Analysis phase: analyze data derived from the LP template
- Improvement phase: use data for next cycle planning

Figure 1 below shows the methodology adopted to develop, implement, and conclude a sequence-oriented framework.

Activity Planning Using LBMS and LPS

Location-based management breaks down a project into physical locations for planning and control. Unlike traditional methods, which start from a Work Breakdown Structure (WBS), location-based planning uses location as the basic unit of planning and control. The Location-Based Management System (LBMS) enhances the traditional Critical Path Method and automates planning using locations. Shreve (1930) introduced the concept of cascading delays to achieve high speed by disconnecting different portions of the work.

Building on this foundation Olivieri et al. (2018) delve into LBMS's potential to optimize workflow and resource utilization in construction schedules. They highlight LBMS's role in structuring workflows to minimize downtime and ensure a continuous flow of activities by mapping tasks to specific locations. This approach reduces resource conflicts and overlaps, thereby enhancing productivity. LBMS also facilitates efficient resource allocation based on the needs of specific locations, mitigating variability in construction processes. Supported by case studies and empirical data, the authors demonstrate how LBMS has successfully improved project outcomes in terms of time, cost, and quality (Olivieri et al. 2018).

These studies collectively underscore LBMS's transformative potential in the construction industry, particularly in enhancing productivity, improving workflow, and optimizing resource usage through a location-centric approach. By leveraging LBMS, construction projects can achieve greater efficiency and effectiveness, driving progress toward project milestones and delivering superior outcomes.

Location Breakdown Structure (LBS) is a critical upfront planning decision in LBMS. It allows for a hierarchical LBS with unlimited hierarchy levels and using the same LBS for all tasks of the same phase decreases complexity and increases the system's power. The key elements of the Location-Based Management System (LBMS) are outlined below, focusing on how tasks, quantities, and durations are defined and calculated within the system.

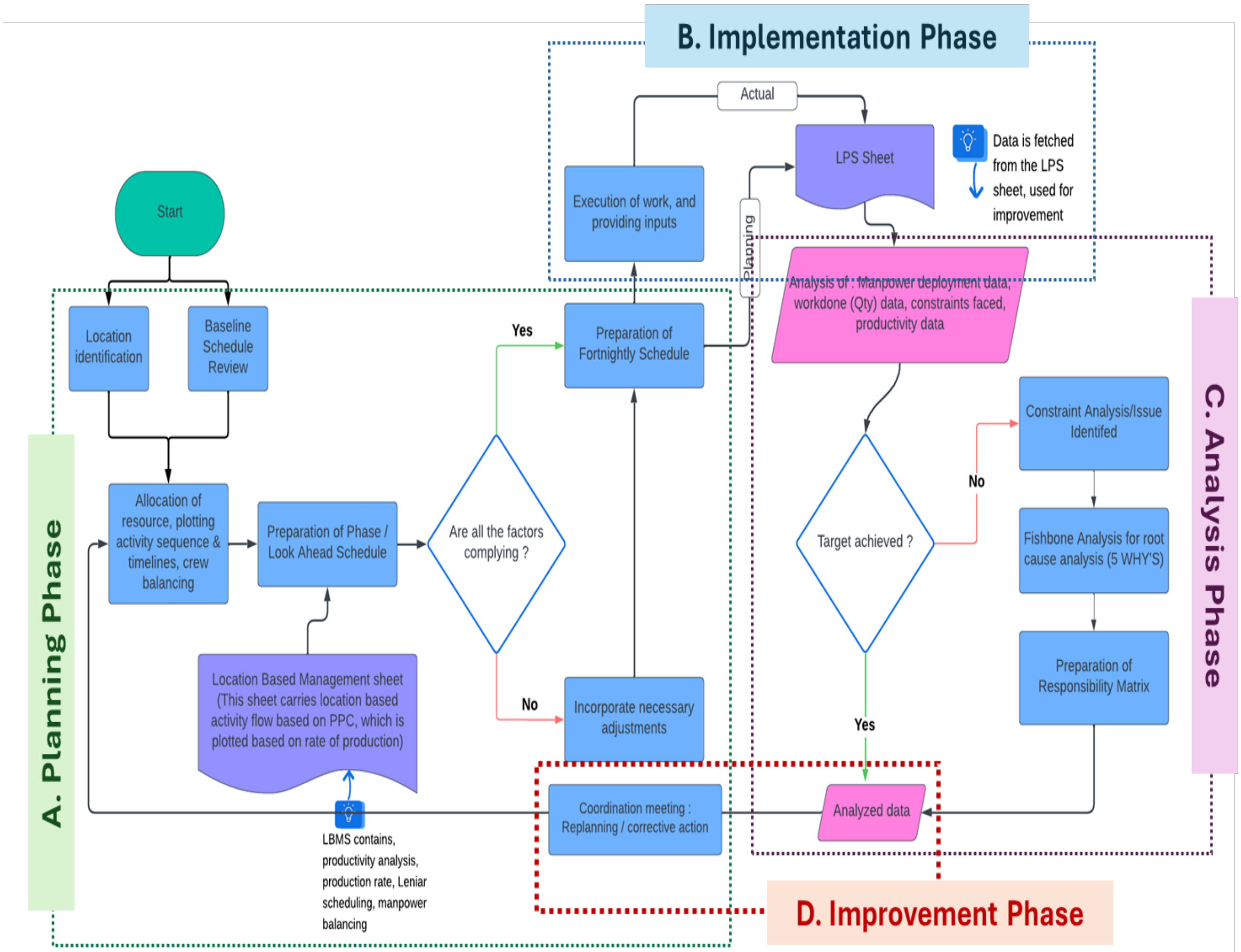


Figure 1 Research Methodology

Task, quantities, and duration calculation - In LBMS, tasks are packages of work completed in one location by the same crew without breaks and sharing the same external dependencies. LBMS assumes that tasks are performed continuously without breaks, and a task's work content can be based on quantities.

Flowline visualization - The quantity of work determines the task's locations and duration, which can be used to plot the flowline of a task.

Risk Management and Buffers - LBMS aims to decrease schedule-related risks by minimizing uncertainties that can affect production. Planning continuous work and adding buffers protect the continuous workflow from variability and minimize the risk of resources not being available when needed.

Schedule Optimization - The optimization process in LBMS focuses on aligning schedules to eliminate empty spaces by changing resources, scope, location sequence, splitting tasks, or switching to discontinuous work. Improving schedule alignment in location-based planning shortens project durations.

Location-Based Controlling System - In LBMS, controlling is prioritized over planning and involves collecting real-time information, reacting to deviations, and proactively managing projects based on actual productivity, progress, and upcoming problems. This includes monitoring the status of locations and labor on-site, visualizing status using control charts and flowlines, and giving alarms to warn of upcoming problems for proactive control.

LBMS monitoring focuses on four aspects:

- Tracking start and finish dates for each location.
- Monitoring actual quantities to detect deviations.
- Calculating actual resource consumption.
- Re-Allocating the new demand as required.

Last Planner System®

The Last Planner System® is a production planning and control technique that has recently come under focus in the construction field as a good practice that can bring about a positive change in project performance. Based on lean construction concepts, LPS supports the implementation of coordination, dependability, and incrementality by involving site supervisors, foremen, and field engineers called the "last planners' to decide work planning and scheduling. LPS entails the Master Schedule and Phase Schedule, at the top strategic level to involve cooperative work, and the Look ahead Plan, at the short-time level to link both. The Weekly Work Plan (WWP) specifies individual tasks, ensuring they meet quality criteria: concerns of definition include; while concerning soundness; it also concerns sequence and size. The rationale is that this system fosters trust in team members, increases overall reliability, and makes it possible for projects to be accomplished within agreed time schedules or timelines, by learning from tasks that were previously accomplished. The key elements of the Last Planner System (LPS) are structured to improve workflow reliability, collaboration, and production control in construction projects. The main components of the Last Planner System are outlined below.

Collaborative Planning: LPS incorporates all stakeholders in the planning process to ensure that they all support the planning process of the business. Making plans can therefore be done correctly, more so through the collaborative work of several people to ensure that the laid down goals can be achieved on the ground.

Master Schedule: It means a master schedule is a planner's output that shows the work that the front-end planner envisions being accomplished throughout the project. This is because it conforms to the critical path method (CPM) logic when determining the overall time of the project and important dates relating to milestones. (Hamzeh et al., 2012).

Look Ahead Plan: This Feature is the most important part of it. Strategies are made at the master level and then managed at the detailed level in the short run, which is usually six weeks to two months. The objective of this process is to gain information on constraints and to determine whether resources are available at any point in time. (Hamzeh et al., 2012). Another step is the weekly plan, their output is seen every week as a reminder of this commitment. The Last Planners are committed to the work they are going to perform based on the consensus as to what is feasible in the given context.

Percent of Plan Complete (PPC): The PPC is an indicator applied by LPS in the context of assessing the efficiency of the planning process. The PPC is measured by the ratio of items planned and completed along with the total number of items planned for that efficiency. It gives a precise measure of how successfully the planning was done compared to the execution (Liu and Ballard, 2008)

Continuous Improvement: LPS has a system of prescribing and revising the planning process regularly. Previous achievements are used to help in the planning and realization of the subsequent work.

Correlation of LPS and LBMS

The integration of Location-Based Management Systems (LBMS) and the Last Planner System has received attention, especially for planning and controlling construction projects. Kenley and Seppänen, (2010) further look at the complimentary impacts of a combination of LBMS and LPS to show how both systems can support the improvement of workflow reliability, dimension of workflow variability, and consequent enhancement of project performance by substantiating the foregoing assertions throughout case studies. They attest to the multifaceted application of this integration, as Kenley and Seppänen (2010) have pointed out how this can indeed assist in construction processes, thus enhancing the workflow.

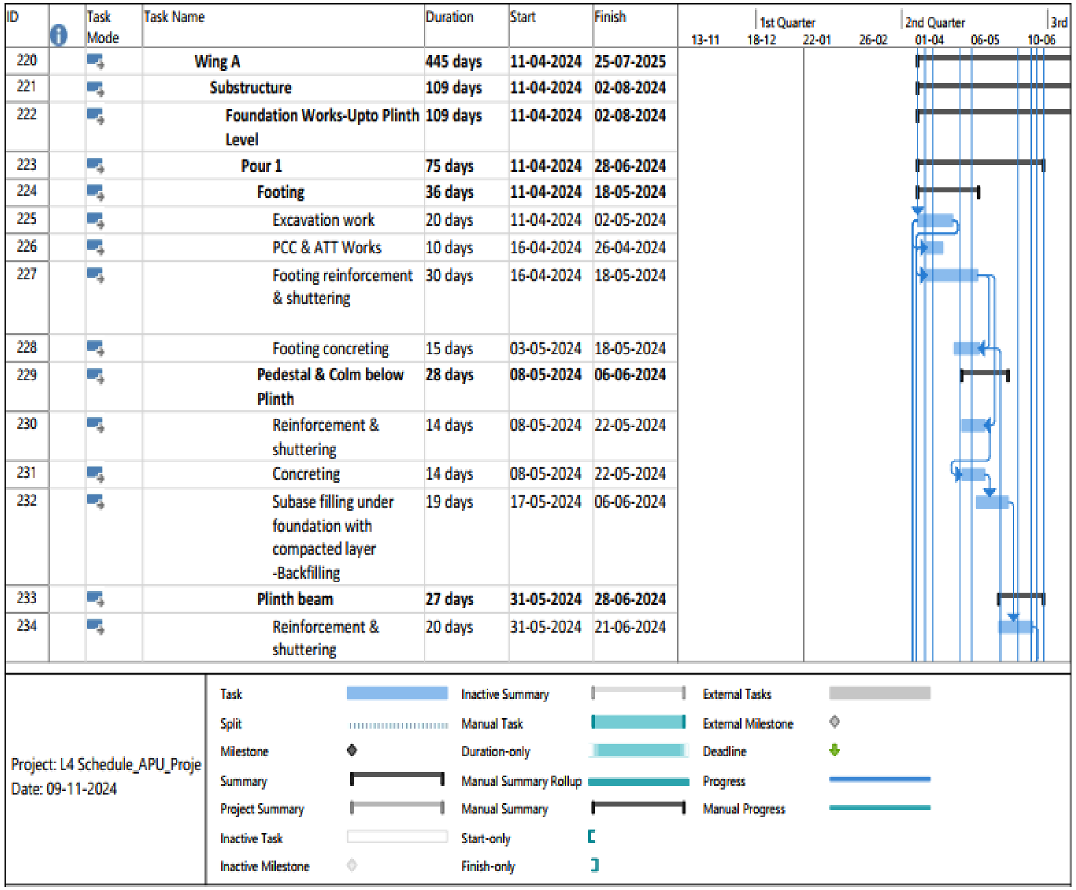
The authors Ballard and Howell (2004) described various difficulties linked to the implementation of both LBMS and LPS, expecting cultural resistance, an unclear definition, and technological problems. They present concrete data extracts from many projects to indicate possibilities for solutions and strategies on how to eradicate such challenges. These are the promotion of collaboration, training, support, and the use of technology to enhance integration (Ballard and Howell, 2004)

In relation to lean construction guidelines, Sacks et al. (2010) examine the effects of implementing of LBMS and LPS. It explains that this partnership contributes to lean practices by focusing on the flow and the elimination of waste while increasing value. In their study, the authors have described case studies where LBMS and LPS have been adopted and clearly show how the integration of this system has led to organizational benefits. (Sacks et al. 2010.) Another advantage reflected upon for project scheduling by Kenley and Seppänen (2010) is that of improved integration of LBMS and LPS. They go through the literature on the integration of these systems and present several instances that demonstrate that this leads to gains in the precision and dependability of the project schedules. Such integration enables the determination of efficient ways of resource use and eradication of delays, hence supporting predictable project deliverables (Kenley and Seppänen, 2010)

Last, the real-time monitoring and control with the help of LBMS and LPS is described by Kenley and Seppänen (2010). Their studies elaborate on how these systems can be integrated to deliver real-time information on the project's progression, where such information is vital in defining differentials to the planned course of action. This real-time information enables the project managers to correct a problem or compensate for an anomaly, hence making projects have better performance or to be on track.

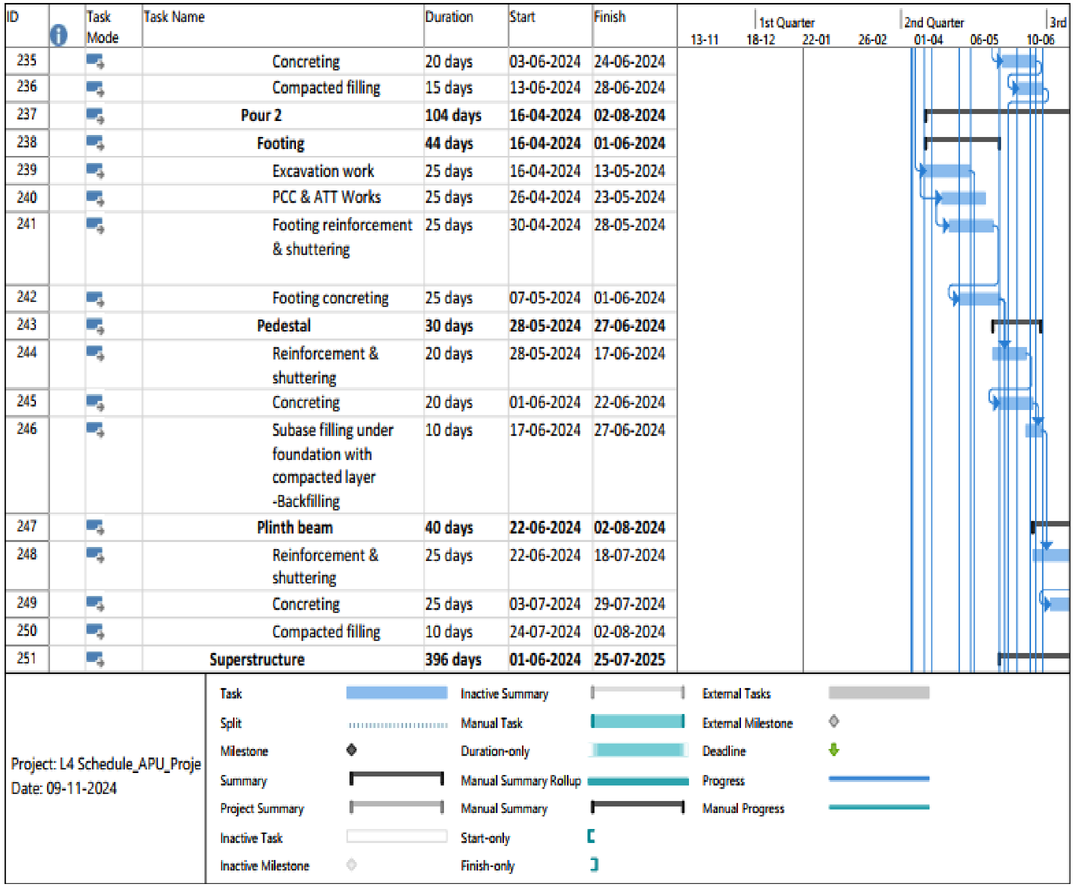
Implementation Steps

In the beginning, the Master Construction Schedule (MCS), as shown in Figure 2, was reviewed for the area under study, i.e. Wing-A of the Academic Block from Foundation Works up to Plinth Level. As per MCS, duration of P1 and P2 was 75days and 104 days, respectively. The MCS was reviewed using LBMS line of balance for better activity visualization.



ID	Task Name	Duration	Start	Finish
220	**Wing A**	**445 days**	**11-04-2024**	**25-07-2025**
221	**Substructure**	**109 days**	**11-04-2024**	**02-08-2024**
222	**Foundation Works-Upto Plinth Level**	**109 days**	**11-04-2024**	**02-08-2024**
223	**Pour 1**	**75 days**	**11-04-2024**	**28-06-2024**
224	**Footing**	**36 days**	**11-04-2024**	**18-05-2024**
225	Excavation work	20 days	11-04-2024	02-05-2024
226	PCC & ATT Works	10 days	16-04-2024	26-04-2024
227	Footing reinforcement & shuttering	30 days	16-04-2024	18-05-2024
228	Footing concreting	15 days	03-05-2024	18-05-2024
229	**Pedestal & Colm below Plinth**	**28 days**	**08-05-2024**	**06-06-2024**
230	Reinforcement & shuttering	14 days	08-05-2024	22-05-2024
231	Concreting	14 days	08-05-2024	22-05-2024
232	Subase filling under foundation with compacted layer -Backfilling	19 days	17-05-2024	06-06-2024
233	**Plinth beam**	**27 days**	**31-05-2024**	**28-06-2024**
234	Reinforcement & shuttering	20 days	31-05-2024	21-06-2024

(a)duration of P1



ID	Task Name	Duration	Start	Finish
235	Concreting	20 days	03-06-2024	24-06-2024
236	Compacted filling	15 days	13-06-2024	28-06-2024
237	**Pour 2**	**104 days**	**16-04-2024**	**02-08-2024**
238	**Footing**	**44 days**	**16-04-2024**	**01-06-2024**
239	Excavation work	25 days	16-04-2024	13-05-2024
240	PCC & ATT Works	25 days	26-04-2024	23-05-2024
241	Footing reinforcement & shuttering	25 days	30-04-2024	28-05-2024
242	Footing concreting	25 days	07-05-2024	01-06-2024
243	**Pedestal**	**30 days**	**28-05-2024**	**27-06-2024**
244	Reinforcement & shuttering	20 days	28-05-2024	17-06-2024
245	Concreting	20 days	01-06-2024	22-06-2024
246	Subase filling under foundation with compacted layer -Backfilling	10 days	17-06-2024	27-06-2024
247	**Plinth beam**	**40 days**	**22-06-2024**	**02-08-2024**
248	Reinforcement & shuttering	25 days	22-06-2024	18-07-2024
249	Concreting	25 days	03-07-2024	29-07-2024
250	Compacted filling	10 days	24-07-2024	02-08-2024
251	**Superstructure**	**396 days**	**01-06-2024**	**25-07-2025**

(b)duration of P2

Figure 2. Master Construction Schedule

Please refer to Table 1 for the MCS's activity codification followed in this study. The codification has been used in LBMS and LPS templates for ease of understanding.

Table 1: MCS Activity Codification

Element	Activity	Pour# 01	LOB Id.	Pour# 02	LOB Id.
Footing	Excavation work	P1EX	1	P2EX	A
	ATT Works	P1ATT-PCC	2	P2 ATT-PCC	B
	Footing reinforcement & shuttering	P1FOOT R/F	3	P2FOOT R/F	C
	Footing concreting	P1FOOTCONC	4	P2FOOTCONC	D
Pedestal &Colm below Plinth	Reinforcement & shuttering	P1 PEDR/F SHUT	5	P2 PEDR/F SHUT	E
	Concreting	P1 PEDCONC	6	P2 PEDCONC	F
	Backfilling	P1FDN BCK FLL	7	P2FDN BCK FLL	G
Plinth beam	Reinforcement & shuttering	P1PB R/FSHUT	8	P2PB R/FSHUT	H
	Concreting	P1PBCONC	9	P2PBCONC	I
	Compacted filling	P1 PB BCK FLL	10	P2 PB BCK FLL	J

Preparation of Initial Phase of Schedule

The MCS does not specify timelines for the sequenced trade activities. Hence, it's difficult to identify conflicts among them, if any. The activities of Table 1 are included in Table 2 with start and end dates as a part of the phase schedule, and subsequently, each activity was represented in LBMS using a basic linear scheduling method.

Table 2: Initial Phase Schedule Timelines

Element	Pour#01				Pour#02					
	Sl#	Act	Dur	Planned (start / end)	Sl#	Act	Dur	Planned (start / end)	Relationship	Buffer (Days)
Footing	1	P1EX	22	11/04/24	A	P2EX	28	16/04/24	Start to Start	5
				02/05/24				13/05/24		
	2	P1ATT -PCC	11	16/04/24	B	P2ATT -PCC	28	26/04/24	Start to Start	10
				26/04/24				23/05/24		
	3	P1FO OTR/ FSHUT	33	16/04/24	C	P2FO OTR/ F	29	30/04/24	Start to Start	14
				18/05/24				28/05/24		
	4	P1FO OTCO NC	12	03/05/24	D	P2FO OTCO NC	26	07/05/24	Start to Start	4
				14/05/24				01/06/24		
	5		15	08/05/24	E		21	28/05/24	Start to Start	20

Element	Pour#01				Pour#02					
	Sl#	Act	Dur	Planned (start / end)	Sl#	Act	Dur	Planned (start / end)	Relationship	Buffer (Days)
Pedestal G Colm below Plinth		P1PED R/F SHUT		22/05/24		P2PED R/F SHUT		17/06/24		
	6	P1PEDCONC	15	08/05/24 22/05/24	F	P2PEDCONC	22	01/06/24 22/06/24	Start to Start	24
	7	P1FDNBCKFLL	21	17/05/24 06/06/24	G	P2FDNBCKFLL	11	17/06/24 27/06/24	Start to Start	31
Plinth beam	8	P1PBR/FSHUT	22	31/05/24 21/06/24	H	P2PBR/FSHUT	27	22/06/24 18/07/24	Start to Start	22
	9	P1PB CONC	28	03/06/24 30/06/24	I	P2PB CONC	27	03/07/24 29/07/24	Start to Start	30
	10	P1PB BCKFLL	16	13/06/24 28/06/24	J	P2PB BCKFLL	10	24/07/24 02/08/24	Start to Start	41

It was observed that the total planned duration for Pour # 01 and Pour #02 has been considered to be 79 days and 109 days, respectively. The flowlines for Pour # 01 and Pour #02 are presented in Figure 3 and Figure4, respectively. While preparing the LBMS chart using basic linear scheduling following conflicts were spotted.

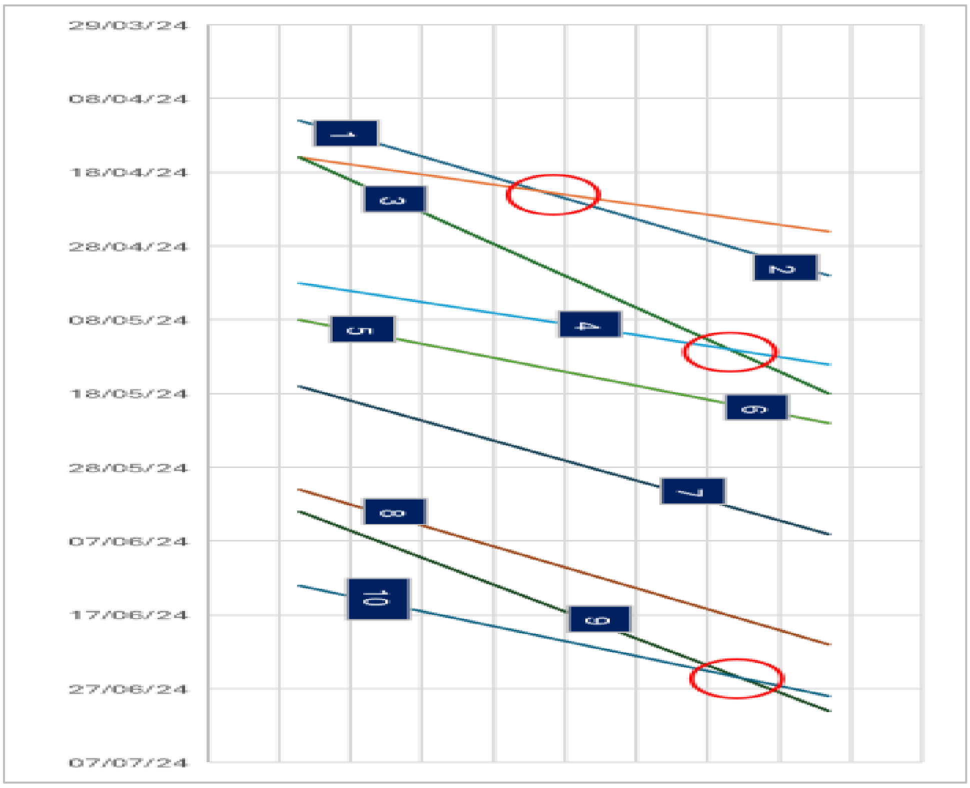


Figure 3. Pour#01 (Initial) Flowline

Conflicts in Pour #01 as shown in Figure 3:

- The rate of production of Activity #02: ATT-PCC work was more than its predecessor Activity # 01: P1 EX.
- The rate of production considered for Activity# 03:P1FOOTR/F SHUT is slower than the successor Activity # 04: P1 FOOT CONC.
- The start and end dates for Activity # 05 and Activity # 06 are the same, which must be changed.
- Between Activity # 07 and Activity # 08, a 14-day buffer has been kept, which is delaying the entire cycle.
- RateofproductionconsideredforActivity#09:P1PBCONCisslowerthanthe successor Activity # 10 : P1 PB BCK FLL.

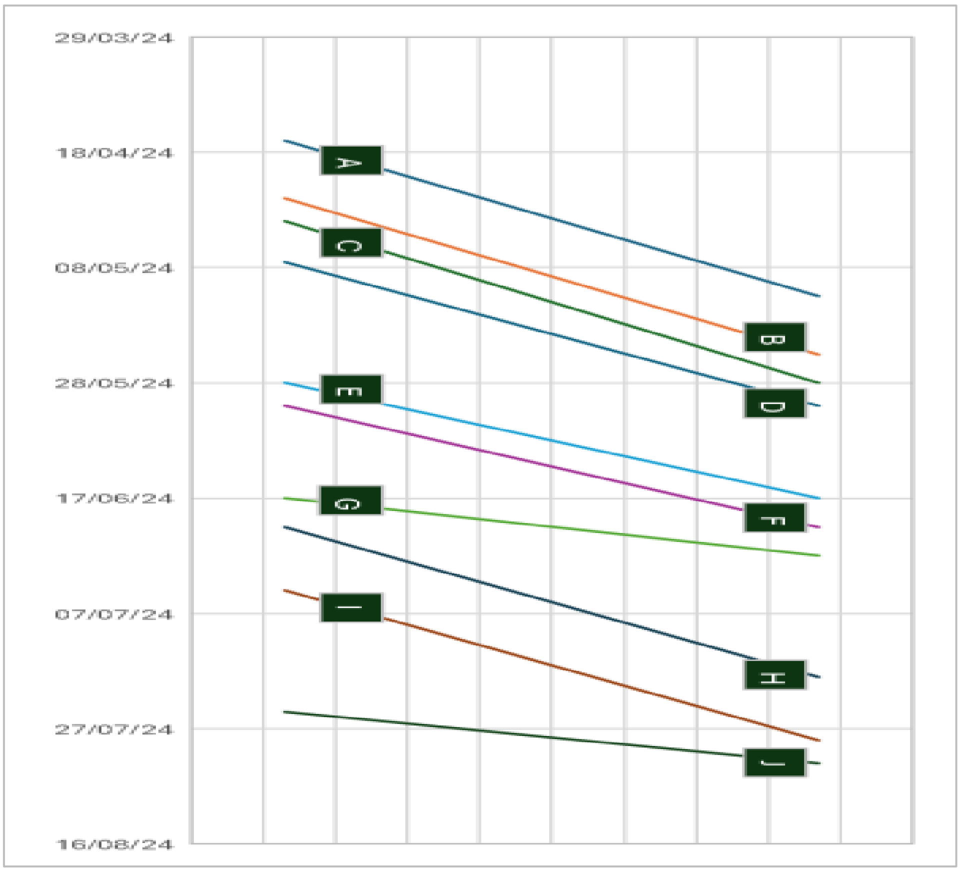


Figure 4. Pour # 02 (Initial) Flowline

As seen in Figure 4 (Conflicts in Pour #02), there was no apparent conflict spotted between activities.

Figure 5 is a combination of both figures of Pour # 1 and Pour # 2 that shows the conflicts between similar activities of both pours. Hence, for both the pours, improvements were possible to remove the conflicts and optimize the planned duration.

Preparation of optimized Phase Schedule

An optimized schedule was prepared, removing the activity conflicts and reducing the planned duration. The revised planned duration for Pour # 01 and Pour # 02 was brought down to 63 days and 82 days respectively. Refer to Table 3 showing the Revised Phase Schedule Timelines.

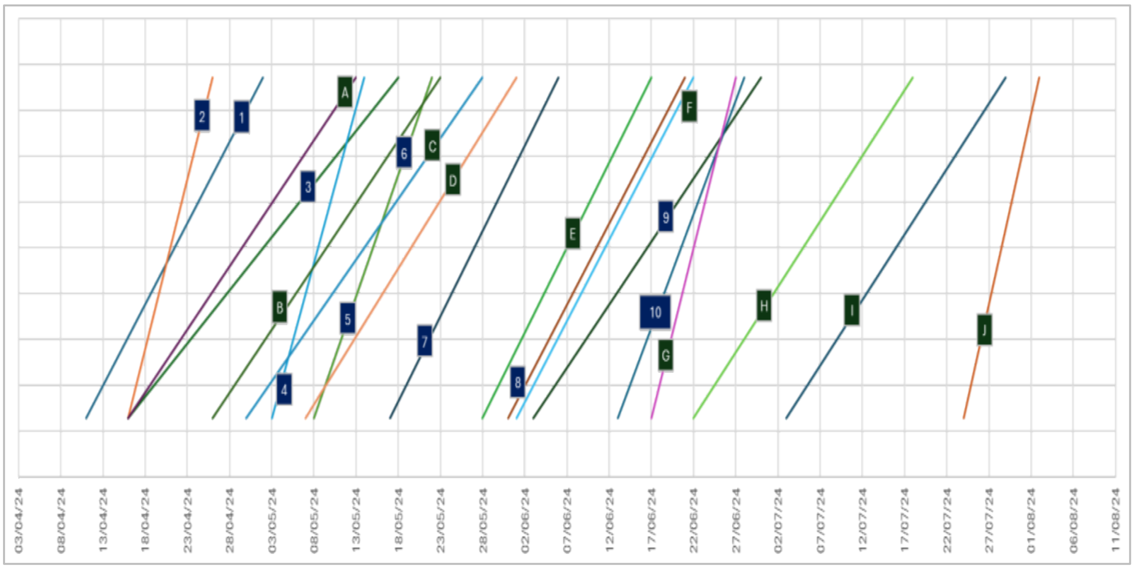


Figure 5. Pour # 01 & 02 Combined (Initial) Flowline as per MCS

Table 3: Revised Phase Schedule Timelines

AcademicBlock2A-G+4/Location: Wing -A						**Dur (Days)**	**P1 →63**		**P2 →82**	
Element	**Pour#01**				**Pour#02**					
	Sl#	**Act.**	**Dur.**	**Planned (start/end)**	**Sl#**	**Act**	**Dur.**	**Planned (start/end)**	**Rel**	**Buffer (Days)**
Footing	1	P1EX	12	11/04/24 22/04/24	A	P2EX	18	16/04/24 03/05/24	Start to Start	5
	2	P1ATT-PCC	12	14/04/24 25/04/24	B	P2ATT-PCC	15	26/04/24 10/05/24	Start to Start	12
	3	P1FOOTR/FSHUT	15	17/04/24 01/05/24	C	P2FOOTR/FSHUT	20	02/05/24 21/05/24	Start to Start	15
	4	P1FOOTCONC	12	24/04/24 05/05/24	D	P2FOOTCONC	20	06/05/24 25/05/24	Start to Start	12
Pedestal G Colm below Plinth	5	P1PEDR/F SHUT	15	29/04/24 13/05/24	E	P2PEDR/F SHUT	22	14/05/24 04/06/24	Start to Start	15
	6	P1PED CONC	12	04/05/24 15/05/24	F	P2PED CONC	23	16/05/24 07/06/24	Start to Start	12
	7	P1FDN BCKFLL	15	11/05/24 25/05/24	G	P2FDN BCKFLL	18	26/05/24 12/06/24	Start to Start	15
	8	P1PBR/FSHUT	18	18/05/24 04/06/24	H	P2PBR/FSHUT	18	05/06/24 22/06/24	Start to Start	18

AcademicBlock2A-G+4/Location: Wing -A							Dur (Days)	P1 →63	P2 →82	
Element	Pour#01				Pour#02					
	Sl#	Act.	Dur.	Planned (start/end)	Sl#	Act	Dur.	Planned (start/end)	Rel	Buffer (Days)
Plinth beam	9	P1PBCONC	20	21/05/24 09/06/24	I	P2PBCONC	23	10/06/24 02/07/24	Start to Start	20
	10	P1PBBCKFLL	13	31/05/24 12/06/24	J	P2PBBCKFLL	24	13/06/24 06/07/24	Start to Start	13

The optimized timelines were then plotted to derive flowlines, each representing an activity as per MCS. To ensure smooth progress it was essential that neither the dependable activities within the same pour nor the activities which would be performed in a sequence by the same crew in both the pours should clash. Figure 6 and Figure 7 depict the planned schedule of both the pours.

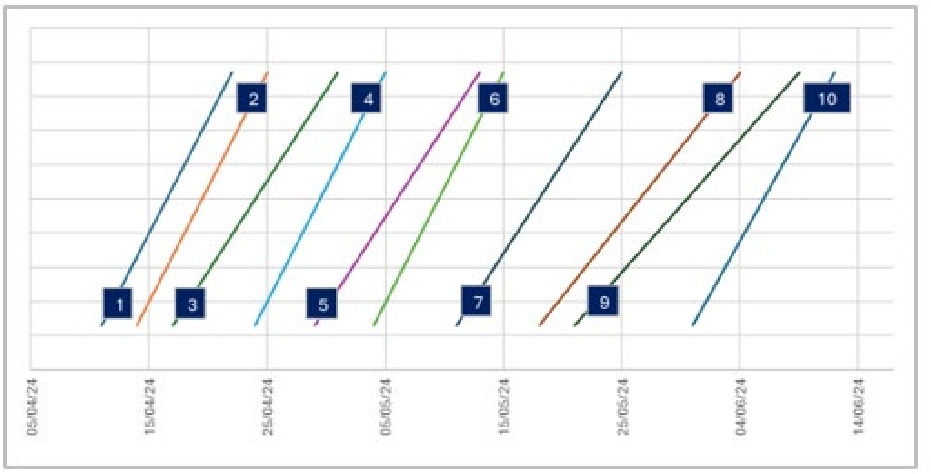


Figure 6. Pour # 01Revised Flow Line

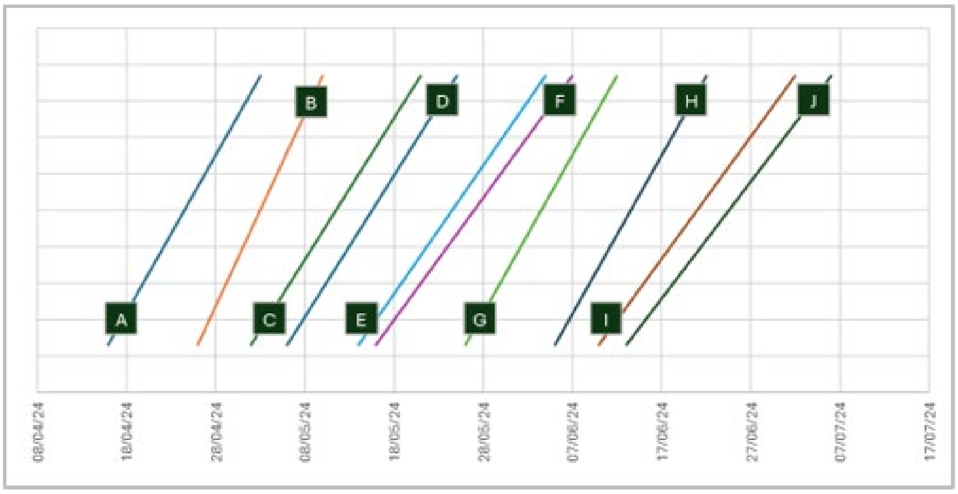


Figure 7. Pour # 01Revised Flowline

Figure 8 depicts the combined schedule of Pour#01and 02where conflicts among both the scenarios mentioned above could be averted.

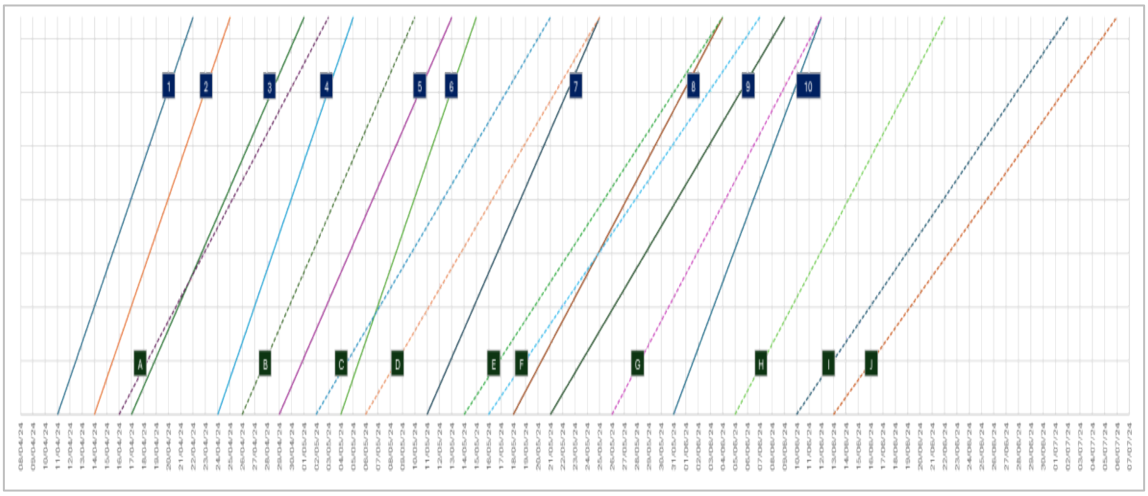


Figure 8. Pour # 01 & 02 Combined Flowline (Revised)

Preparation of Location Breakdown Structure

The MCS activities were broken down into further detailed sub-activities and the sequence of activities was established between Pour # 01 and Pour # 02. A crew balancing chart was developed, depicting the manpower movement. While planning, the quantity of work and the desired productivity norms were considered as per Table 4a and Table 4b.

Table 4a: Productivity Calculation - Planned vs Achieved

Pour #01

Project: **Azim Premji University, Bhopal** Location: **Academic Block | Foundation** Production Rate Cum Productivity Analysis

Sl No	Activity	Activity Code	Plan/Actual	Duration (Days)	Start Date	End Date	Qty	Production /Day	Manpower/Day	Productivity (UOM/Man-day)	% Achieved
1	Excavation Work	P1EX	Planned	12	11-04-24	22-04-24	5500	458	3	180	68%
			Actual	15	11-04-24	25-04-24		367	3	122	
2	ATT Works	P1ATT	Planned	11	14-04-24	24-04-24	1450	132	1	250	15%
			Actual	13	17-04-24	29-04-24		112	3	37	
3	PCC @ Foundation	P1PCC	Planned	11	15-04-24	25-04-24	43	4	1	4	15%
			Actual	18	18-04-24	05-05-24		2	4	0.60	
4	Footing Reinforcement	P1FOOTR/F	Planned	14	17-04-24	30-04-24	54	3.857	31	0.125	60%
			Actual	18	16-04-24	06-05-24		3	40	0.08	
5	Footing Shuttering	P1FOOTSHUTT	Planned	13	16-04-24	01-05-24	881	68	16	3.50	64%
			Actual	22	21-04-24	12-05-24		40	18	2.22	
6	Footing Concreting	P1FOOTCONC	Planned	12	24-04-24	05-05-24	537	45	11	4	57%
			Actual	21	02-05-24	22-05-24		26	11	2.3	

Sl No	Activity	Activity Code	Plan/Actual	Duration (Days)	Start Date	End Date	Qty	Production /Day	Manpower/Day	Productivity (UOM/Man-day)	% Achieved
7	Pedestal + Column Reinforcement	P1PEDR/F	Planned	6	26-04-24	07-05-24	7.5	0.833	7	0.125	16%
			Actual	21	05-05-24	25-05-24		0	15	0.024	
8	Pedestal + Column Shuttering	P1PED SHUT	Planned	11	03-05-24	13-05-24	436	40	13	3	64%
			Actual	19	09-05-24	27-05-24		23	12	1.9	
9	Pedestal + Column Concreting	P1PED CONC	Planned	12	04-05-24	15-05-24	60	5	1	4	63%
			Actual	19	14-05-24	01-06-24		3	1	2.5	
10	Plinth Beam Reinforcement	P1PBR/F	Planned	16	18-05-24	02-06-24	29	1.813	15	0.125	56%
			Actual	23	30-05-24	21-06-24		1	18	0.07	
11	Plinth Beam Shuttering	P1PBSHUT	Planned	16	20-05-24	04-06-24	960	60	14	4.1	68%
			Actual	19	07-06-24	25-06-24		51	18	2.8	
12	Plinth Beam Concreting	P1PBCONC	Planned	20	21-05-24	09-06-24	286	14	5	3	100%
			Actual	20	09-06-24	28-06-24		14	5	3	

Table 4b: Productivity Calculation - Planned vs Achieved

Pour #02

Project: **Azim Premji University, Bhopal** Location: **Academic Block | Foundation** Production Rate Cum Productivity Analysis

Sl No	Activity	Activity Code	Plan/Actual	Duration (Days)	Start Date	End Date	Qty	Production/Day	Manpower/Day	Productivity (UOM/Man-day)	% Achieved
1	Excavation Work	P2EX	Planned	18	16-04-24	03-05-24	4900	272	2	180	41%
			Actual	22	18-04-24	09-05-24		223	3	74	
2	ATT Works	P2ATT	Planned	12	26-04-24	07-05-24	1445	120	2	250	18%
			Actual	11	29-04-24	09-05-24		131	3	44	
3	PCC @ Foundation	P2PCC	Planned	13	28-04-24	10-05-24	46	4	1	4	130%
			Actual	10	05-05-24	14-05-24		5	1	5.20	
4	Footing Reinforcement	P2FOOTR/F	Planned	13	02-05-24	14-05-24	56	4	32	0.125	75%
			Actual	15	08-05-24	22-05-24		4	40	0.093	
5	Footing Shuttering	P2FOOTSHUTT	Planned	18	04-05-24	21-05-24	627	35	20	2	83%
			Actual	24	13-05-24	05-06-24		26	18	1.45	
6	Footing Concreting	P2FOOTCONC	Planned	20	06-05-24	25-05-24	545	27	7	4	105%
			Actual	16	22-05-24	06-06-24		26	7	4.2	
7	Pedestal + Column Reinforcement	P2PEDR/F	Planned	11	14-05-24	24-05-24	8	0.727	6	0.125	16%
			Actual	27	24-05-24	19-06-24		0	15	0.02	

Sl No	Activity	Activity Code	Plan/Actual	Duration (Days)	Start Date	End Date	Qty	Production/Day	Manpower/Day	Productivity (UOM/Man-day)	% Achieved
8	Pedestal + Column Shuttering	P2PED SHUT	Planned	11	25-05-24	04-06-24	448	41	15	2.72	36%
			Actual	38	26-05-24	02-07-24		12	12	0.68	
9	Pedestal + Column Concreting	P2PED CONC	Planned	23	16-05-24	07-06-24	74	3	1	4	56%
			Actual	39	28-05-24	05-07-24		2	1	2.36	
10	Plinth Beam Reinforcement	P2PBR/F	Planned	15	05-06-24	19-06-24	32	2	17	0.125	53%
			Actual	27	17-06-24	13-07-24		1	18	0.07	
11	Plinth Beam Shuttering	P2PBSHUT	Planned	17	06-06-24	22-06-24	1160	68	20	3.41	64%
			Actual	20	26-06-24	15-07-24		58	18	3.22	
12	Plinth Beam Concreting	P2PBCONC	Planned	23	10-06-24	02-07-24	341	15	4	4	74%
			Actual	31	28-06-24	28-07-24		11	4	2.97	

For Anti Termite Treatment (ATT) only one crew of 2 workers was planned, starting the work at Pour # 01 and directed to Pour # 02 (Figure9). For the reinforcement activity, refer to Figure 11, the work planned at Pour# 01 footing by 30 workers (Crew 1), moving to Pour #02 footing. A second crew (Crew2) of 10 workers was planned for pedestal & column reinforcement at Pour # 01, who would move to Pour # 02 and exit.10 workers from Crew 1, after completion of Pour#02 footing, would exit for another location, and 20 workers were planned for Pour # 01 plinth beam reinforcement works. These 20 workers would subsequently move to Pour #02, plinth beam, and exit for another location post-completion. Refer to Figure 10.

Crew movement for shuttering and de-shuttering activity followed reinforcement activity. Refer to Figure 10, Figure 11, and Figure 12. The planned manpower is shown in the respective figure with Crew #.

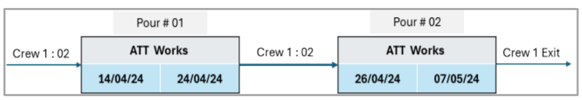


Figure 9. ATT Crew Balancing

Activity	UOM	Pour # 1 (QTY)	Pour # 2 (QTY)
Ex	Cum	5500	4900
ATT	SQM	1450	1445
PCC	Cum	43	46
Foot Shut	SQM	881	627
Foot R/F	MT	5.40	5.60
Foot Conc	Cum	537	545
PED + COL Shut	SQM	439	448
PED + COL R/F	MT	7.50	8.0
PED + COL Conc	Cum	60	74
PB Shut	SQM	960	1160
PB R/F	MT	29.0	32
PB Conc	Cum	289	341

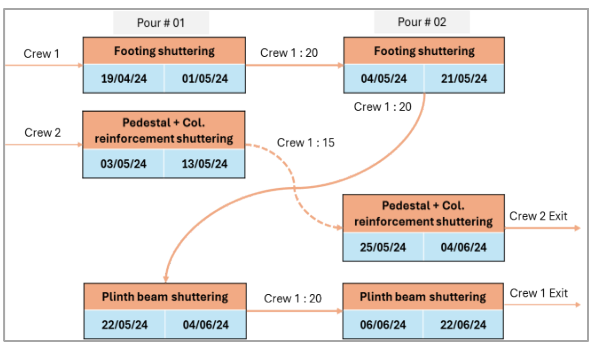


Figure 10. Shuttering Crew Balancing

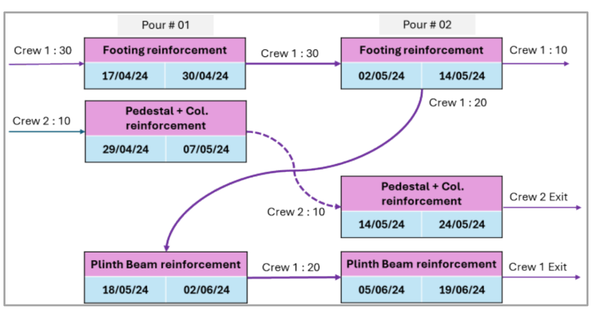


Figure 11. Reinforcement Crew Balancing

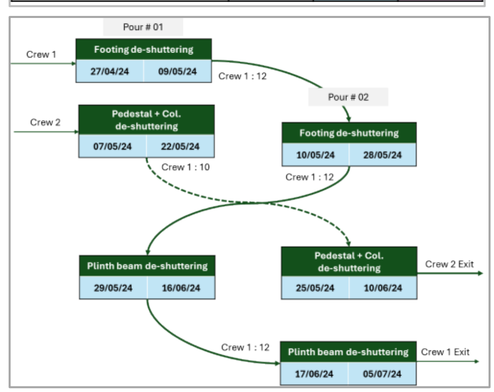


Figure 12. De-shuttering Crew Balancing

Preparation of Percent Plan Complete (PPC) Based Phase Schedule

The activity flow line and the crew balancing chart gave a fair idea about the planned activities and their mutual progress over the duration. The schedule of both pours was compressed to accommodate any delays to the MCS. However, the activities further needed to be viewed in terms of the rate of production and to connect the LBMS phase schedule to the LPS template. The LPS template is required to begin with relevant details. To develop a production-based schedule, a common unit of production was to be determined, which would enable plotting of each key activity. Percent Plan Complete (PPC) was selected for this purpose, as the work planned and executed for any activity can easily be translated into PPC. Therefore, the LBMS template for monitoring was connected to the LPS template, which, when filled, updates the former for easy calculation. Figure 13 describes all the activities represented by the PPC-based flow line diagram. Having a timeline-based LBMS phase schedule (Table 3), crew balancing diagrams (Refer Figure 9, Figure 10, Figure 11 and Figure 12), and PPC-based LBMS schedule enabled the preparation of a Fortnightly Work Schedule in a designated template prepared as per LPS guidelines.

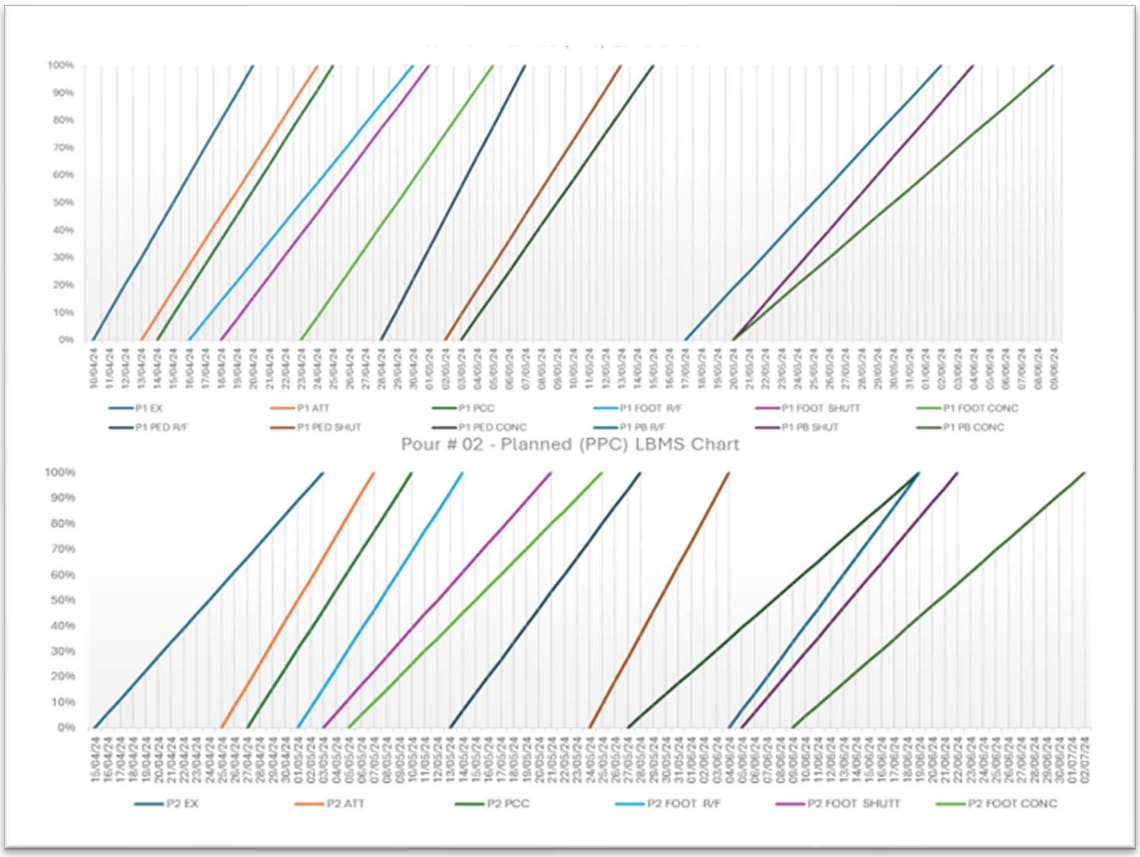


Figure 13. Planned (PPC) Based Phase Schedule

Preparation of LPS – Look Ahead Schedule

Once the phase schedule was finalised, activities were listed in a designated template showing week-wise progress. Each relevant stakeholder was consulted to give their input, and a Monthly Look Ahead Plan was finalised (Figure 14). Each activity was given a target each day, beginning from the start to the end. Two types of identical schedules were prepared based on the following two factors,

1. The production rate, which was planned during the LBMS phase schedule.
2. Man-days, to be deployed for each activity over the planned duration

The availability and requirement of resources for the targets under the look-ahead period were documented and communicated to the relevant stakeholders

Project : Azim Premji University _Bhopal		Yr : 2024			lay	May	May	May	May	May	May	May	May	May	May	May	May	May	May	May	June	June
Academic Block | Substructiure | Foundation up to plinth					Week 13				LAP : Week 14							LAP : Week 15						
Four Week Look Ahead Plan |		Mandays / Day			hu	Fri	Sat	Sun	Mon	Tue	Ved	Thu	Fri	Sat	Sun	Mon	Tue	Ved	Thu	Fri	Sat	Sun
Sl #	Activity	QTY	Start Dt	End dt.	05/24	17/05/24	18/05/24	19/05/24	20/05/24	21/05/24	22/05/24	23/05/24	24/05/24	25/05/24	26/05/24	27/05/24	28/05/24	29/05/24	30/05/24	31/05/24	01/06/24	02/06/2
1	Excavation work	72	11/04/24	03/05/24																		
2	ATT Works	46	14/04/24	07/05/24																		
3	PCC @ foundation	96	15/04/24	10/05/24																		
4	Footing reinforcement	990	17/04/24	14/05/24	30	30	30	30	30	30												
5	Footing shuttering	500	19/04/24	14/05/24																		
6	Footing concreting	320	24/04/24	25/05/24	10	10	10	10	10	10	10	10	10	10								
7	Footing deshuttering	384	27/04/24	28/05/24	12	12	12	12	12	12	12	12	12	12	12	12	12					
8	Pedestal + Col. reinforcement	145	29/04/24	24/05/24	5	5	5	5	5	5	5	5	5									
9	Pedestal + Col. shuttering	330	03/05/24	04/06/24										15	15	15	15	15	15	15	15	15
10	Pedestal + Col. Concreting	129	04/05/24	07/06/24	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
11	Pedestal + Col. deshuttering	330	07/05/24	10/06/24	10	10	10	10	10	10	10			10	10	10	10	10	10	10	10	10
12	Foundation Backfilling	66	11/05/24	12/06/24	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
13	Plinth Beam reinforcement	620	18/05/24	19/06/24			20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
14	Plinth Beam shuttering	660	20/05/24	22/06/24					20	20	20	20	20	20	20	20	20	20	20	20	20	20
15	Plinth Beam concreting	215	21/05/24	02/07/24						5	5	5	5	5	5	5	5	5	5	5	5	5
16	Plinth Beam deshuttering	456	29/05/24	05/07/24														12	12	12	12	12
17	Plinth Beam Backfilling	72	31/05/24	06/07/24																2	2	2
	Total Mandays	5431	Duration :	87																		

Manpower Requirement

SR. NO.	LABOR TYPE	NAME OF SUPPLIE R / PRW	TOTAL REQD PER DAY	TOTAL REQD FOR THE MONTH
1	Carpenter		1330	34580
2	Carpenter Helper		1330	34580

Material Requirements

SR.NO.	MATERIAL DESCRIPTION	UOM	TOTAL QTY. REQD	VEEK 1	VEEK 2	VEEK 3	VEEK 4	VEEK
1	Cement	MT	6867.20	1373.44	1373.44	1373.44	1373.44	1373.44
2	GGBS	Ton	1716.80	343.36	343.36	343.36	343.36	343.36

Project : Azim Premji University _Bhopal		Yr : 2024			May	May	May	May	May	May	May	May	May	May	May	May
Academic Block | Substructiure | Foundation up to plinth						LAP : Week 12							LAP : Week 13			
Four Week Look Ahead Plan | Production Rate : QTY/Day					Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu
Sl #	Activity	QTY	Start Dt	End dt.	05/05/24	06/05/24	07/05/24	08/05/24	09/05/24	10/05/24	11/05/24	12/05/24	13/05/24	14/05/24	15/05/24	16/05/24
1	Excavation work	10401	11/04/24	03/05/24												
2	ATT Works	2890	14/04/24	07/05/24	120	120	120									
3	PCC @ foundation	96	15/04/24	10/05/24	4	4	4	4	4	4						
4	Footing reinforcement	135435	17/04/24	14/05/24	4310	4310	4310	4310	4310	4310	4310	4310	4310	4310	4310	4310
5	Footing shuttering	1268	19/04/24	14/05/24	35	35	35	35	35	35	35	35	35	35		
6	Footing concreting	1077	24/04/24	25/05/24	45	27	27	27	27	27	27	27	27	27	27	27
7	Footing deshuttering	1511	27/04/24	28/05/24	68	68	68	68	68	33	33	33	33	33	33	33
8	Pedestal + Col. reinforcement	15494	29/04/24	24/05/24	833	833	833							727	727	727
9	Pedestal + Col. shuttering	891	03/05/24	04/06/24	40	40	40	40	40	40	40	40	40			
10	Pedestal + Col. Concreting	129	04/05/24	07/06/24	5	5	5	5	5	5	5	5	5	5	5	3
11	Pedestal + Col. deshuttering	874	07/05/24	10/06/24			27	27	27	27	27	27	27	27	27	27
12	Foundation Backfilling	5187	11/05/24	12/06/24							173	173	173	173	173	173
13	Plinth Beam reinforcement	61003	18/05/24	19/06/24												
14	Plinth Beam shuttering	2116	20/05/24	22/06/24												
15	Plinth Beam concreting	634	21/05/24	02/07/24												
16	Plinth Beam deshuttering	2128	29/05/24	05/07/24												
17	Plinth Beam Backfilling	3744	31/05/24	06/07/24												
			Duration :	87												

Figure 14. Monthly Look Ahead Schedule

Preparation of LPS – Fortnightly Schedule

The look-ahead plan was divided into blocks of 15 days and a Fortnightly Schedule (Figure 15) was prepared in line with the Look Ahead Schedule. The collaboration with other teams through coordination meetings ensured contribution and commitment from all stakeholders. Resource updates were collected from relevant teams and supporting activities were included in the list of activities. After finalization, the schedules were circulated to the execution team to collect daily updates on the following factors:

1. Man-days deployed against planned.
2. Quantity (tentative) of work done against the planned.
3. Reason for non-achievement when a target is not met.

Project Name:		Azim Premji University _Bhopal		Excavation (CuM):		5500	RF ST-1Y	SH-ST-2 Y	SH-2 Y	AI-1 Y	MEP-1Y	SH-3 N	SH-9 N	MEP-2 N	SH-5 N	SH-6 N	SH-8 NC	RF-5 N
Building:		Academic Block 2A-G+4		Floor Area (Sq.M):		2280	RF ST-1Y	SH-ST-2 Y	SH-2 Y	AI-1 Y	MEP-1Y	SH-3 N	SH-9 N	MEP-2 N	SH-5 N	SH-6 N	SH-8 NC	RF-5 N
Location:		Foundation		Rebar Quantity (MT):		90.5	Pour 1 – Fortnightly Qty Schedule : 2											
Pour:		1 – Phase 1		Concrete Quantity (CuM):		929	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day
SI #	Activity Code	Activity	lanned / Actu	Planned/ Actual	Start Dt	End dt.	26/04/24	27/04/24	28/04/24	29/04/24	30/04/24	01/05/24	02/05/24	03/05/24	04/05/24	05/05/24	06/05/24	07/05
1	P1 EX	Excavation work	Planning	12	11/04/24	22/04/24												
			Actual	15	11/04/24	25/04/24												
2	P1 ATT-PCC	ATT Works	Planning	11	14/04/24	24/04/24												
			Actual	16	17/04/24	29/04/24	3	3	3	3								
3	P1 PCC	PCC @ foundation	Planning	11	15/04/24	25/04/24												
			Actual	18	18/04/24	05/05/24	6	6	6	6	6	6	6	6	6	6		
4	P1 FOOT R/F	Footing reinforcement	Planning	14	17/04/24	30/04/24	4231	4231	4231	4231	4231							
			Actual	18	19/04/24	06/05/24	40	40	40	40	40	40	40	40	40	40	40	
5	P1 FOOT SHUTT	Footing shuttering	Planning	13	19/04/24	01/05/24	46	46	46	46	46	46						
			Actual	22	21/04/24	12/05/24	18	18	18	18	18	18	18	18	18	18	18	18
6	P1 FOOT CONC	Footing concreting	Planning	12	24/04/24	05/05/24	34	34	34	34	34	34	34	34	34	34		
			Actual	21	02/05/24	22/05/24							8	8	8	8	8	8
7	P1 FOOT DSH	Footing deshuttering	Planning	13	27/04/24	09/05/24		47	47	47	47	47	47	47	47	47	47	47
			Actual	21	09/05/24	29/05/24												
8	P1 PED R/F	Pedestal + Col. reinforce	Planning	9	29/04/24	07/05/24				596	596	596	596	596	596	596	596	596
			Actual	21	05/05/24	25/05/24										15	15	15
9	P1 PED SHUT	Pedestal + Col. shutterir	Planning	11	03/05/24	13/05/24								27	27	27	27	27
			Actual	19	09/05/24	27/05/24												

Figure 15. Fortnightly Schedule

Controlling Production

The execution teams followed the Fortnightly Schedule provided to them. After each day's work, the achieved work values were updated in the targeted column, as shown in Figure 16. If the target could not be achieved, the reasons were documented and used in the constraint analysis.

Project Name:		Azim Premji University _Bhopal		Excavation (CuM):		5500	EP-1Y	SH-3 N	SH-9 N	MEP-2 N	SH-5 N	SH-6 N	SH-8 NC	RF-5 N	RF-6 N	RF-7 N	MEP-3 N	SH-10 N
Building:		Academic Block 2A-G+4		Floor Area (Sq.M):		2280	EP-1Y	SH-3 N	SH-9 N	MEP-2 N	SH-5 N	SH-6 N	SH-8 NC	RF-5 N	RF-6 N	RF-7 N	MEP-3 N	SH-10 N
Location:		Foundation		Rebar Quantity (MT):		90.5	Pour 1 – Fortnightly Mandays Schedule : 2											
Pour:		1 – Phase 1		Concrete Quantity (CuM):		929	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 1
SI #	Activity Code	Activity	lanned / Actu	Planned/ Actual	Start Dt	End dt.	0/04/24	01/05/24	02/05/24	03/05/24	04/05/24	05/05/24	06/05/24	07/05/24	08/05/24	09/05/24	10/05/24	11/05/24
			Actual	16	17/04/24	29/04/24												
3	P1 PCC	PCC @ foundation	Planning	11	15/04/24	25/04/24												
			Actual	18	18/04/24	05/05/24	6	6	6	6	6	6						
4	P1 FOOT R/F	Footing reinforcement	Planning	14	17/04/24	30/04/24	30											
			Actual	18	19/04/24	06/05/24	40	40	40	40	40	40	40					
5	P1 FOOT SHUTT	Footing shuttering	Planning	13	19/04/24	01/05/24	20	20										
			Actual	22	21/04/24	12/05/24	18	18	18	18	18	18	18	18	18	18	18	18
6	P1 FOOT CONC	Footing concreting	Planning	12	24/04/24	05/05/24	8	8	8	8	8	8						
			Actual	21	02/05/24	22/05/24			8	8	8	8	8	8	8	8	8	8
7	P1 FOOT DSH	Footing deshuttering	Planning	13	27/04/24	09/05/24	12	12	12	12	12	12	12	12	12	12		
			Actual	21	09/05/24	29/05/24										8	8	8
8	P1 PED R/F	Pedestal + Col. reinforce	Planning	9	29/04/24	07/05/24	10	10	10	10	10	10	10	10				
			Actual	21	05/05/24	25/05/24						15	15	15	15	15	15	15
9	P1 PED SHUT	Pedestal + Col. shutterir	Planning	11	03/05/24	13/05/24				15	15	15	15	15	15	15	15	15
			Actual	19	09/05/24	27/05/24										12	12	12
10	P1 PED CONC	Pedestal + Col. Concreti	Planning	12	04/05/24	15/05/24					8	8	8	8	8	8	8	8
			Actual	19	14/05/24	01/06/24												
			Planning	[illegible]	10/05/24	22/05/24											10	10

Figure 16. Fortnightly Schedule - Mandays

Quantity values entered by execution teams in the Fortnightly Schedule were copied into the PPC-based LBMS chart so that each day's executed work gets converted into a percentage coefficient of the targeted quantity. This gave a clear understanding of planned vs actual progress of activities. The flow lines of actual activities have been shown by dotted lines, and the planned lines have been shown by the grey solid lines, as shown in Figure 17. The deviations/ delays from the planned lines are clearly visible. The delays have been recorded by the execution teams in the Fortnightly Schedule sheet; however, the LBMS flow lines gave a relatively better picture.

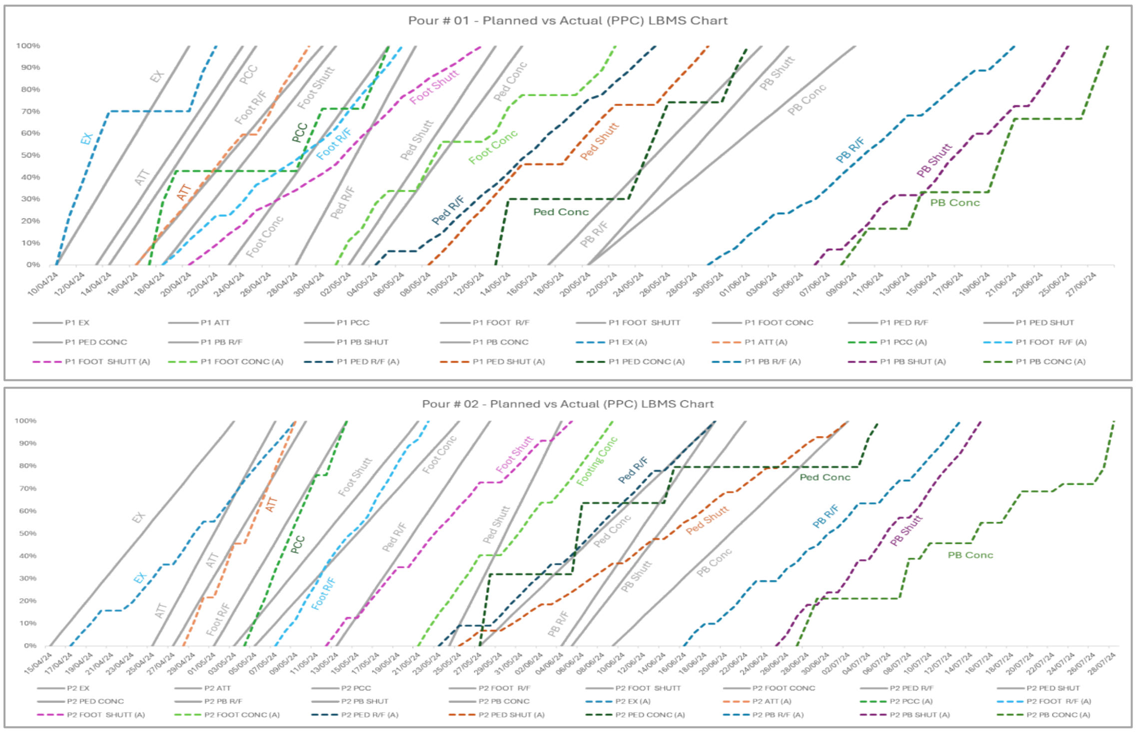


Figure 17. Actual (PPC) Based Phase Schedule

Thus, the integration of the Location-Based Management System and the Last Planner System has been achieved through the stages of reviewing, planning, execution, and further monitoring. The information gathered from the phase schedule and look-ahead schedule prepared following LBMS guidelines were used fortnightly planning template prepared using LPS guidelines. Subsequently, deviations recorded in fortnightly planning were analysed, and actionable points were identified through root cause analysis.

Constraint Analysis

Constraints were gathered through the fortnightly schedule's constraints register; Figure 18. Constraints were noted by site execution team members as and when they were faced.

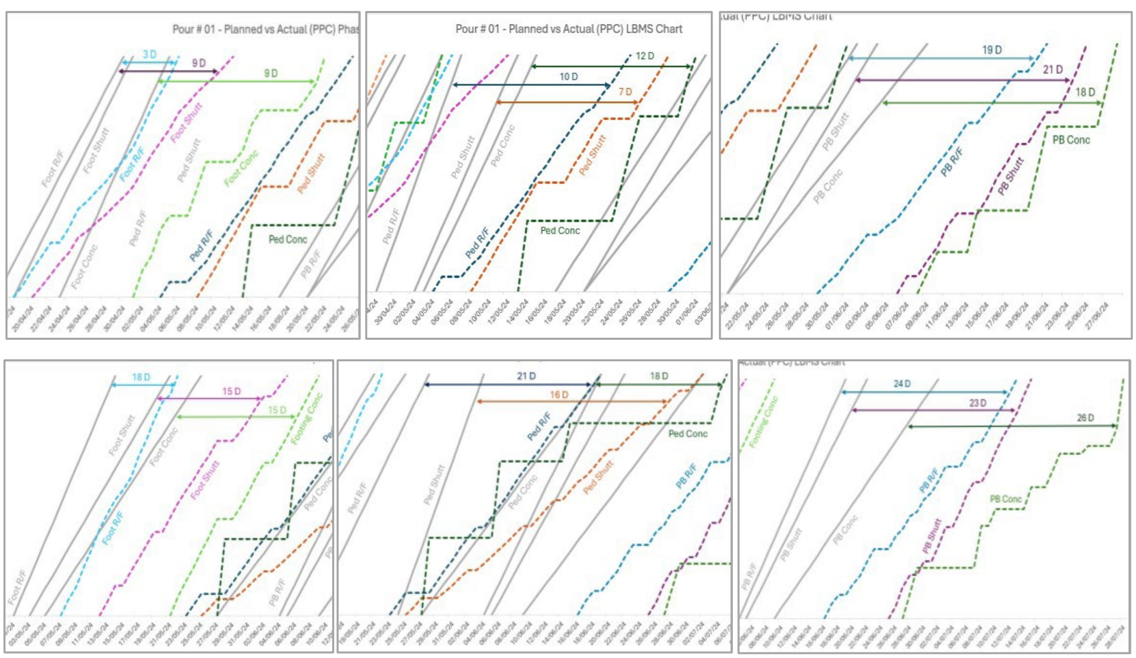
Issues were discussed in site coordination meetings.This study focuses on the constraints that had a direct impact on the following factors,

1. Activity delay, delay percentage against planned duration.
2. Productivity variation, percentage achieved against planned.

Project : APU, Bhopal				Constraints Sheet				
Sr. no.	Date	Location	Activites	Work Details	Assigned Person/Accountable	Cause/Problem	Main Constraint	Issues Faced
1	6/10/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Layout of footing		NA		
				Rebar Installation		Error in rebars	Material	Unable to fit the rebars on time
				Curing of PCC		Supply is delayed	Material	Supply is less
2	6/11/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Layout of footing		NA		
				Rebar Installation		NA		
3	6/12/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Layout of footing		NA		
				Rebar Installation		NA		
				Shuttering		Supply is delayed	Material	Material Not Available
4	6/13/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Shuttering		NA		
5	6/14/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Shuttering		Defect in material	Material	Size of material
				Pouring of Concrete				
6	6/15/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Shuttering		NA		
				Pouring of Concrete		Material Delyaed	Material	Not having enough quantity to order
7	6/16/2024	Academic Block	Footing work	Grid-K	Rejaul/Vaibhav			
				Shuttering		NA		
				Pouring of Concrete		NA		
				Deshuttering		NA		

Figure 18. Constraint register

The actual duration of Pour # 01 was 89 days against the planned 63 days as per the optimised phase schedule and 79 days as per the master construction schedule. In the case of Pour # 02, the actual duration was 115 days against the planned duration of 82 days and 109 days as per the MCS.Delays in individual activities became apparent when PPC data from the Fortnightly Schedule were copied into PPC based LBMS chart (Figure 19).



Visibledelaybetweenactivityflowlines Pour#02

Figure 19. Visible delays in PPC Based Phase Schedule

Pour#01was delayed by 26days and Pour#02 was delayed by 34days with respect to the optimized phase schedule. The delay was attributed to all three critical activities i.e. reinforcement works, shuttering works, and concreting works. Reinforcement activity took 9 days more, shuttering took 9 days, and concreting works took 7 days more at every level from footing to plinth beam level. Delays from the said activities had a cascading effect on the subsequent ones, causing delayed cycles for both the pours, refer to Figure 20.

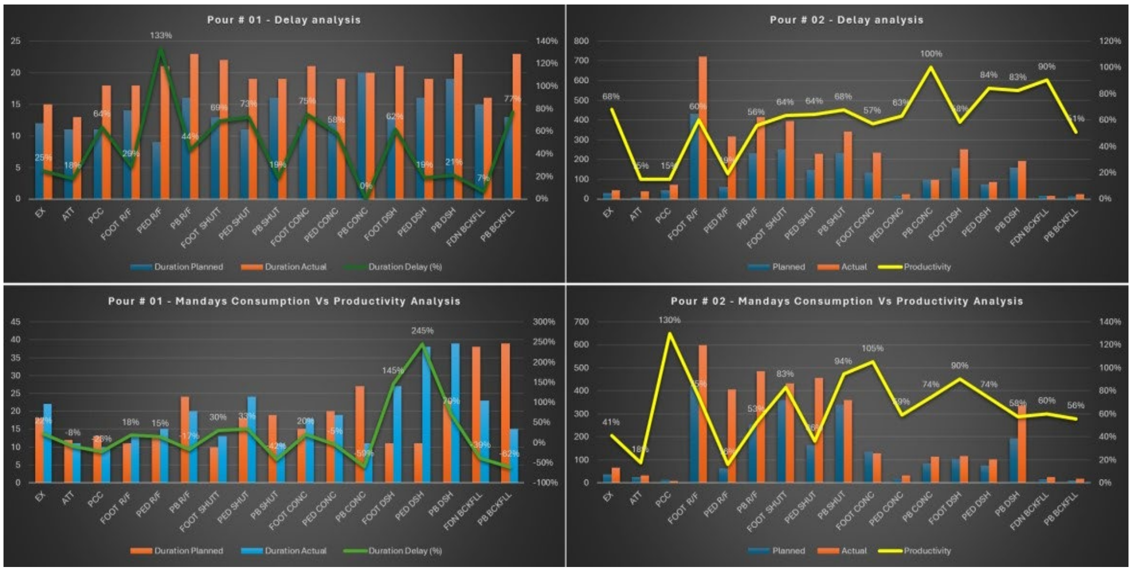


Figure 20. Delay and productivity Analysis

Root cause analysis was done on the deviations or non-achievements reported by the execution teams. Repeated or frequently reported issues were taken for analysis of root cause. The root causes were decided based on inputs from relevant stakeholders during site coordination meetings.

To analyze the root causes of identified issues, an established tool, 'Fishbone Analysis' was used. Figure 21 states the identified root causes. The following critical points were identified in line with the fishbone diagram:

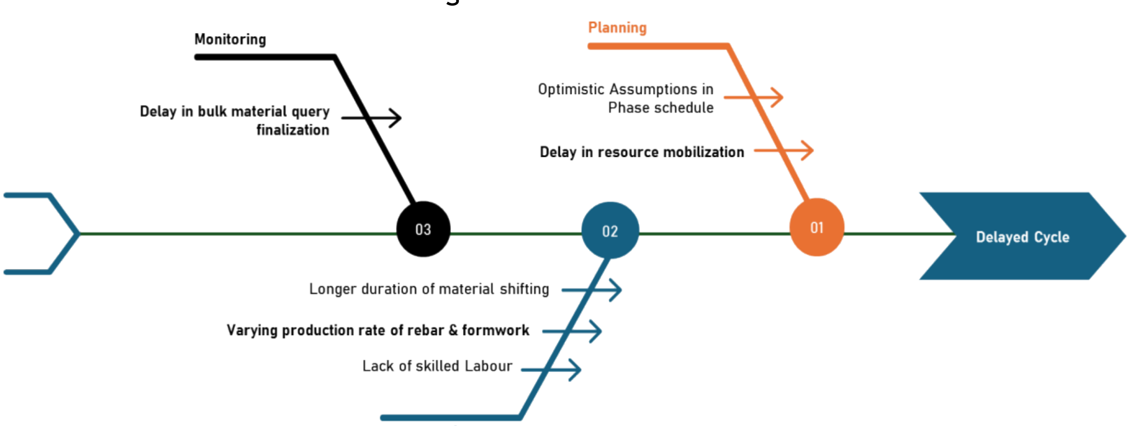


Figure 21. Fishbone diagram

- Inconsistent concrete delivery due to the finalization of the bulk material query
- Production gap in reinforcement and formwork shuttering teams
- Delay in resource mobilization
- Schedule optimization was too strict

Corrective Action (CA) Taken

Along with root cause analysis, corrective action plans were developed to address the root causes, preventing further recurrence of the issues. Action plans were communicated to the appropriate functions. The action plan, as shown in Figure 22, included responsibilities assigned with target dates assigned to the relevant functions.

ProjectFunctionalCollaborationmeeting																
PROJECTNAME:	APU,Bhopal											PROJECTMANAGER:				
Location:	HOMP											PreparedBy:				
MOM						RACI MATRIX						TRACKING				
SR.NO.	AGENDA	DISCUSSIONHELD	TASKDESCRIPTION/ACTIONSDECIDED	ORIGIN	CATEGORY	NAME	FUNCTION	LEVEL	NAME	FUNCTION	LEVEL	%ofPROGRESS	DUEDATE	STATUS	UPDATEDON	REMARKS
1				Client/Consultant	Drawing		Projectin Charge	Site	Mr.Y			0%	7/10/2023	NotStarted	7/10/2023	
2				SPE&C	Approval		Planning	RO				10%	2/7/2023	In Progress	2/7/2023	
3				Sub-Contractor	Material		Billing/Commercial	HO				20%	2/6/2023	Complete	2/6/2023	
4					Manpower		Execution-Civil					30%		Needs Review		
5					Equipment		Execution-STR.Steel					40%		Approved		
6							Execution-MEP					50%		Overdue		
7							Q A&C					60%		OnHold		
8							HSE					70%				
9							PnM					80%				
10							Stores					90%				
11							Admin					100%				
12							Procurement									
13																

Figure 22. Sample Responsibility Matrix for CA

Re-Planning of Next Cycles

Activities were replanned which included adjustments in phase schedules, resource allocation, manpower balancing, and other necessary steps to improve productivity and operational performance. Apart from productivity improvement, the project team was required to take steps to enhance administrative efficiencies.

Effective Site Coordination Meeting

Enhancing collaboration with external providers was proposed, especially to acquire middle management level employees and increase the number of skilled workforce. This would have ensured stricter monitoring execution. Awareness amongst the existing team about the purpose of the framework and the required flow of information was explained.

Mitigating Skill gap

A trade competency test was proposed to be conducted at the project before deploying the new workforce. Hand skill training and activity mock-ups were proposed to enhance the productivity of the existing workforce.

Future scope

The proposed framework demands the availability of accurate and consistent data regularly. The process gets complex as the scope of work widens. Therefore, enhancement through automation, streamlining processes, and enabling real-time data collection and analysis using digital platforms is required. This allows for quicker identification and resolution of bottlenecks, improving overall project efficiency.

Exploring other applications for this framework can extend its benefits to quality control, safety management, and supply chain optimisation. Additional tools like Value Stream Mapping, Kanban boards, and Six Sigma can be integrated to address specific project needs.

Customizing the framework for different departments in construction such as design, engineering, procurement, and on-site management can maximize its utility. Collaboration with experts from these areas can improve the templates used and workflows.

Conclusions

In conclusion, the integration of Lean Construction principles, specifically through the Last Planner System (LPS) and Location-Based Management System (LBMS), through processing data by both the tools and analysing them effectively showed significant promise, addressing challenges in resource balancing and productivity enhancement. By focusing on minimizing waste, enhancing workflow reliability, and optimizing resource utilization, these methodologies have improved project efficiency and performance.

The project-based research demonstrated the practical application of these tools in real-world construction projects. Using Fishbone Diagrams and, the RACI matrix, systematically identified and mitigated bottlenecks, ensuring better control on project execution.

Despite encountering implementation challenges such as site scale and manpower limitations during the mobilization stage, the framework's benefits in reducing discrepancies between planned and actual work quantities were evident, as illustrated in the research methodology.

Looking forward, the framework can be further refined and expanded by leveraging automation, integrating additional tools, and tailoring it to suit specific departmental needs within construction. This evolution promises to enhance project outcomes, promote sustainability, and foster a culture of continuous improvement in the construction industry.

In essence, the journey towards leaner, more efficient construction practices is ongoing. By embracing collaborative planning, real-time monitoring, and systematic problem- solving, the industry can build upon these foundations to achieve higher standards of quality, reliability, and client satisfaction in construction projects worldwide.

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