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Lean Design to Lean Construction:
Integrating the Last Planner System with Concurrent Engineering

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Abstract

This case study integrates design and construction management by applying the Last Planner SystemTM (LPS) and Concurrent Engineering (CE) on a 64-classroom construction project. The study employed an observation technique to collect data. At the same time, the Percentage Plan Complete (PPC) of planned activities was measured against planned day releases or weekly releases of completed portions of work. The project's PPC was 83%, and some critical activities were completed on time due to the designers applying concurrent engineering concepts. These included reinforcing a suspended slab with a universal beam, reinforced retaining double-walled and floor beams, French drains and adjusting the roof cover to build around a mature fruit tree. The inputs and solutions by the last planners were instrumental in shaping the design and construction of the project in 24 weeks (168 days). The study concludes that there are benefits in applying lean construction tools and that training all project stakeholders on how to use them is essential. The study recommends adopting organisational learning in activity planning to create realistic weekly plans. The importance of last planners is also emphasised to improve the efficiency of site operations. Managing variations by design consultants is critical in reducing delays and improving project quality and cost performance.

Keywords: Waste, value, lean construction, Last Planner System (LPS), Concurrent Engineering (CE)

INTRODUCTION

The construction industry is characterised by inefficient production systems (Larsen et al. 2016 & Gomez-Cabrera et al. 2019). These manifest through delays, cost overruns and poor quality (waste or non-value adding activities). Studies have noted that 70% of projects experience time overruns (delays) while 28% experience cost overruns (Cwik & Roslon, 2017; Atapattu et al., 2022). An analysis of the Swedish public infrastructure projects identified design and planning processes as causes of cost overruns (Lind & Brunes, 2015). Lean construction is a management philosophy that aims to reduce waste and optimise value to the customer (internal and external customers).

This case study proposed that addressing a project's cost, time, and quality issues should begin in the pre-construction phase and not only in the construction phase. Baseline project schedules were established, and subsequent revisions were made; cost estimates, detailed project budgets, and cost control measures were implemented.

The study used an exploratory approach to implement the Last Planner System (LPS) and Concurrent Engineering (CE) on a new School Classrooms, Dining Hall and Administration Block remodelling project. The client, designers, and contractors have a previous working relationship. The construction project manager has used aspects of LPS (pull planning techniques) on previous similar projects and was keen to implement other lean construction tools. The study used observation and limited semi-structured interviews with key personnel; structured observation techniques were used to collect data from a literature review and areas of interest to understand the LPS.

THEORY

The Last Planner System (LPS)

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The Last Planner System (LPS) is a production tool that encourages the creation of a predictable workflow among various project actors to realise reliable and consistent results (Ballard, 2011). The Last Planner System prepares a reverse-phase schedule with collaborative planning involving suppliers, subcontractors, site supervisors and foremen (Ballard & Howell, 2003). These Last Planners are encouraged to attend planning meetings as schedules are developed so that there is process ownership. The Last Planners can define how and when work is implemented, minimising challenges that would occur later (Ballard, 2011).

Ballard (2011) contends that LPS can increase plan reliability. In a survey, Cho and Ballard (2011) established a correlation between the implementation of the Last Planner System and cost and time performance on select projects.

The Last Planner System has a control tool where performance is measured against established targets and deviations can be corrected quickly (Ballard & Howell, 2003). The handoffs between various teams involved in a phase of work are the focal points for control, e.g. handoff between steel fixers and concreting team (**Figure 1**). Detailed weekly work plans were proposed to aid in identifying to whom work would be released. Ballard and Howell (2003) contend that the LPS can be improved by measuring the Percentage Plan Complete (PPC) against planned day or weekly releases.

Pull Planning (Scheduling)

Pull planning is a concept where resources (labour, materials, information, plant and equipment) arrive at the required time and place in the right quantities and quality to ensure the production flow on a site continues uninterrupted (Ghosh et al., 2017). Pull scheduling aims to reduce inventories by studying upstream (predecessors) activities and downstream (successors) activities and aggregating the required resources from previously completed tasks so that the activities downstream can start and finish on time. In pull scheduling, activities commence with all the required resources, unlike push planning (traditional planning), where activities start with a partial set of required resources and stoppages happen along the production cycle (Ghosh et al., 2017). Therefore, the production flow in pull scheduling is ensured by modifying the sequence of activities from the initial schedule without affecting the overall master schedule.

Therefore, Pull Planning addresses the challenges of delayed material delivery leading to idle equipment and labour (Satolo et al., 2021). In traditional planning, equipment and labour are kept waiting for certain portions of work to be ready (material available) for succeeding activities

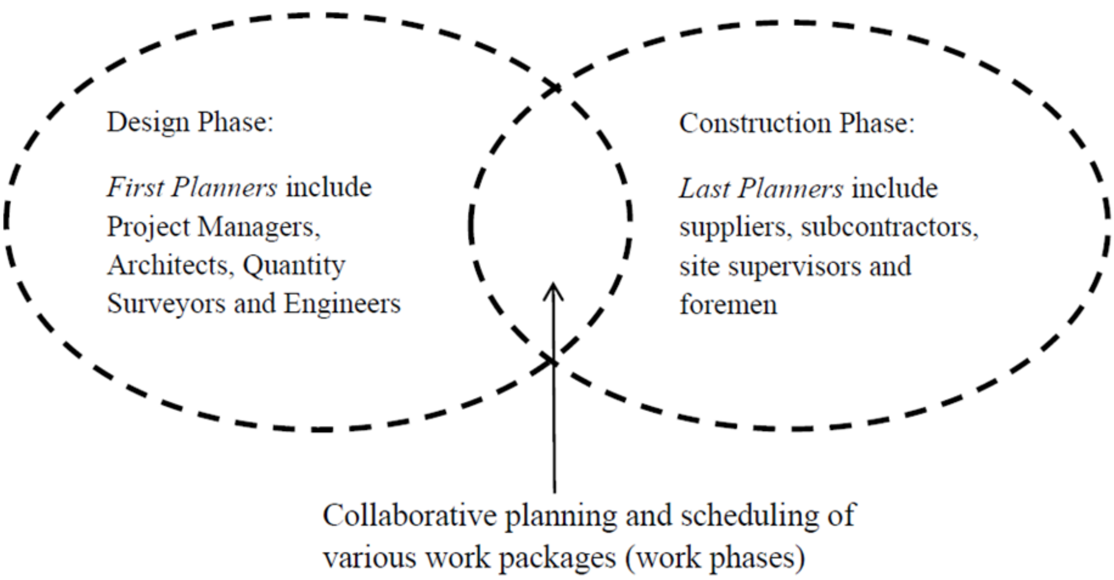

FIGURE 1
The Last Planner System
Source: Field survey, 2025

to start, e.g., cured plaster, while the supply of paint in the required quantity and quality is delayed (Tommelein 1998 in Hosseini 2012). **Figure 2** shows the relationship between cost and value when Pull Planning is applied to a production system. The client is deemed to earn more value as the project progresses when resources are optimised to keep the project running.

Concurrent Engineering (CE)

Concurrent Engineering (CE) is an integrated process encompassing the concurrent design of products and production processes to reduce the cost and time to deliver the final product (Kamara, 2003). Concurrent Engineering has two guiding principles: integration and concurrency. It considers the lifecycle aspect of projects and utilises information and knowledge obtained from various construction phases to generate ideas and areas of improvement. The tools and technology used in these phases are also considered (Kamara, 2003; Safdari, 2018).

Concurrent Engineering (CE) aims to harmonise the interaction of resources (people and tools) and the attendant schedule of tasks to achieve the desired project. At the heart of CE as a tool used in the construction industry is the integrated planning at the organisation level (Quantity Surveyors, Project Managers, Architects, Engineers, and Contractors firms) and project level and the collaboration with supply chain actors (suppliers) (Safdari, 2018).

The study's independent variables are the first and last planners, while the dependent variables are the percent plan complete, the concurrent engineering tools applied, and the observations recorded.

RESEARCH METHODS

This case study is a theory testing research that tests the explanatory power of the Last Planner System (LPS) and Concurrent Engineering (CE) holistically (Dul et al., 2008). The proposed research methodology is Design Science Research Methodology (DSRM) to develop a designed solution (artefact) based on how organisations can benefit from existing lean construction tools and how further knowledge can be developed in this emerging construction management philosophy (Venable et al, 2016). This case study's artefact is to develop a model for integrating the last planner system with concurrent engineering based on a Construction Management form of procurement.

The DSRM has been used to move from theory and apply some of the lean construction tools

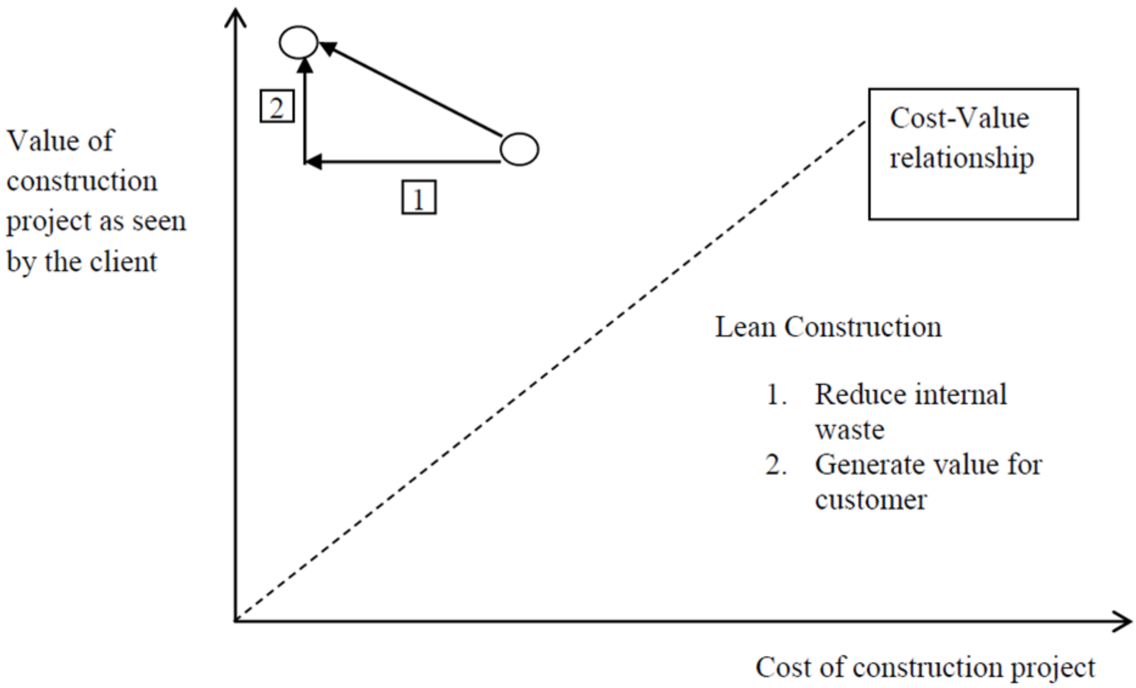

FIGURE 2
Value / Cost Tradeo
Source: Adapted from Satolo et al., 2021

developed by previous studies in lean construction (Da Rocha et al., 2012). Horváth (2007) and Baskerville et al. (2015) reported the goals of DSR as the use of knowledge to solve problems, create changes, or improve existing solutions. The DSR involves the study of research design actions between explorative and confirmatory research actions, i.e. Design Inclusive Research (hereafter referred to as DIR). In short, DIR divides DSR into three stages (Horváth, 2007): to investigate the application of the last planner system and concurrent engineering, and generate hypotheses; to develop and evaluate solutions; and to validate the research and generalise it to other applications.

The case study sought to confirm the validity and applicability of the Last Planner System (LPS) and Concurrent Engineering principles from design to construction of a school's classrooms and associated facilities project. Using the observation method to collect data, the study documented the application of LPS and concurrent engineering.

The observation and interviews were possible because data were observed and recorded from daily site diaries (inputs made by the client's representative). Pull planning techniques, LPS, and Concurrent Engineering were used in the design and construction phase of the project. The initial project time was scheduled to be twelve (12) weeks (phase 1) and ten weeks (phase 2), while the project budget was US$1,860,000.

The Architects, Structural Engineers, Electrical and Mechanical Engineers, Quantity Surveyor/Project Manager, Site Supervisor, and Clerk of Works, construction management contractor, nominated subcontractors and suppliers, were interviewed, and activity and site data were collected through a structured site diary. Project documents were used to plan and implement site activities with site operatives. The design consultants and the contractors on site were at hand to implement concurrent engineering for some essential aspects of the project to ensure and improve functionality, especially for access areas.

The study noted that a confidentiality agreement existed between the client and all consultants and contractors, which was upheld before, during, and after data collection. The client approved that sensitive information that had no bearing on the case study/research would be kept private and confidential.

The DSRM (**Figure 3**) approach uses the following six research steps. Although the study may not have to start with the first step, it is recommended to go through all the steps, depending on the research's entry level (Peffers et al., 2007).

The sampling frame consists of the conceptual framework that underpins the planning and scheduling of design and construction activities. The case was selected based on significant success in implementing lean design and construction tools in previous projects. The project team (client organisation, consultants, main contractor and sub-contractors) previously worked on three other projects. This single case study focuses on

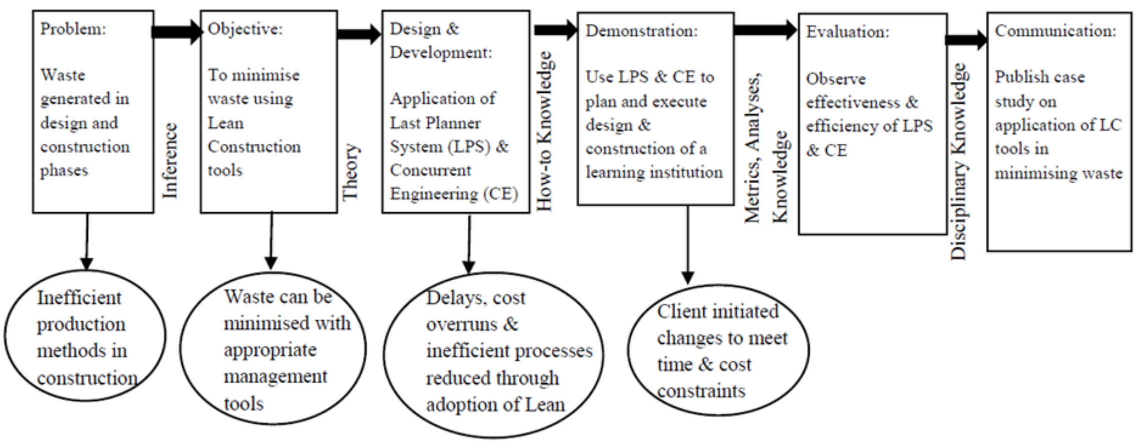

FIGURE 3
Design Science Research Methodology (DSRM)
Source: Field survey, 2025

an in-depth analysis of planning and scheduling tools, including the last planner system and concurrent engineering. The data for the study were weekly planned activities drawn from the project schedule, which were tracked against actual progress on site at the end of each work week. Concurrent engineering opportunities were incidental and were based on challenges that arose as the project progressed. Data was analysed using frequency techniques, and line charts were plotted to map out the project's progress over its two phases. Content and thematic analyses were used to evaluate the application of concurrent engineering in the case study.

RESULTS

The project comprised 64 classrooms with washrooms, a dining hall, external works, and remodelling of an existing building, which was then converted to an administration block. The classrooms project was implemented in two phases (phase 1: June to August 2024; and phase 2: November to December 2024). The classrooms' building has ramped access, twin staircases, and a lift for accessing the different floors. The client desired to phase the project due to time and cost constraints. The scheme design provides a well-lit four (4) cluster arrangement (4 classrooms per cluster) with a lobby in the middle, open spaces in a quadrant plan, and accessible washrooms at the periphery of the building. The case study's thematic areas revolve around the planning and execution of weekly activities, active management of resource planning and constraints (last planner system), and commitment to continuous learning and improvement (concurrent engineering). The case study details are shown in **Table 1**.

The initial cost estimate was based on concept design, which was shared with the client and architect. The first structural design consisted of a framed structure with columns, floor beams, and solid slabs. The cost of the structural design

TABLE 1
Case study details

	Case Study
Type of Project	Classrooms, toilets, Art & Music Rooms, Dining Hall, and Administration Block
Period of the Project	June 2024 to August 2024 & November 2024 to December 2024
Area	64 classrooms, toilets, art & music rooms, dining hall and administration block (6,800 M2)
Type of Study	Case Study
Time Horizon & Location	Cross-sectional study, Nairobi, Kenya
Design Stages	Developed and technical/detailed
Construction Stage	Substructures, Superstructure Reinforced Concrete, Roofing Openings, Walling and Finishes
Evidence Sources	Direct observation, documents
	Observation and documentation by the Construction Project Manager for the following: Design Manager (client), Site Manager, and Architects.
Research activities and participants' roles	Structural Engineer; Main Contractor; Electrical and Mechanical Engineers; MEP subcontractors; aluminium and paint subcontractors
Companies involved	Construction Company; Architectural Office; Engineering Offices; Construction Project Management Office; Quantity Surveying Office; Client
Evaluation	Internal and external evaluation with study participants through documentation and communication
Activities	Design and Construction Planning and Control using Last Planner System and Concurrent Engineering

Source: Kioko, Masu & Rukwaro, 2025

for substructure works, reinforced concrete superstructure frame, mild steel roof structure, and roofing cover raised the project's cost beyond the initial estimate. The client had received another concept design option: a steel structural frame resting on a regular foundation with stub columns complete with anchor bolts to receive base plates, and 175mm reinforced concrete suspended slabs with permanent galvanised steel sheet formwork. This option met the client's time constraint requirement, but caused the initial estimate to be exceeded.

The client requested an alternative structural design solution suitable for the site (shallow foundation), design requirements, cost, and time constraints. The structural engineer redesign comprised a strip foundation, with only eight (8) columns in the lobby area, floor beams, and EPS composite suspended slab (option 3 - **Table 2**) instead of the initially proposed 225mm thick solid slab and load-bearing walls. This revised design brought the cost below the initial estimate, which the client accepted, and proposed that the scheme designs be developed.

The Engineer had proposed a mild steel roof structure and roofing sheet cover, which would be removed every time the project was extended in phases. The prospective contractor, client and project manager suggested that this roof design would be expensive due to the need to remove it, hoist it by crane to a designated point and the lack of space and the restrictions the crane would have to access the site and the furthest corner of the building (68m away). The Quantity Surveyor (the construction project manager) shared the cost of crane hire, which formed the basis for adopting a flat roof construction (in phases) until the building is complete. The cost of the composite slab was the same as the mild steel roof and cover cost.

Design Process and Project Delivery System

The architect developed detailed designs based on load-bearing walls, and the client engaged a proposed contractor to provide design input. The contractor has previous construction experience on the same site, having been involved in the construction of a storehouse, a changing room for the swimming arena, and additional classrooms. The input by the contractor was instrumental in the structural engineering redesign because the average excavation depths on the site were about 1200mm deep. Further, the client is knowledgeable in construction matters (16 years practising as an architect and project manager).

The adopted procurement method was separate prime contractors, each signing contracts with the client. The client has working relationships with material and equipment suppliers, and the proposed supply chain management was for the client to purchase all materials and contractors engaged on labour-only contracts. The construction project manager prepared a project schedule (24-week programme for phases

TABLE 2
Analyses of structural design options

COST CENTRE	GROUP ELEMENT/ELEMENT	TOTAL COST OF ELEMENT (TARGET COST IN US$)
	Superstructure	
Option 1	Mild Steel Frame	165,607.63
	First floor (T Beam and Block)	69,095.39
		234,703.02
Option 2	Mild Steel Frame	165,607.63
	First floor (150mm thick Solid Slab)	64,130.24
		229,737.87
Option 3	Reinforced Concrete Frame (Load Bearing Walls, Beams, & Slab)	4,977.52
	First floor (265mm thick Composite EPS Slab)	86,672.09
		91,649.61

Source: Kioko, Masu & Rukwaro, 2025

1 and 2) and material and equipment forecasts and shared them with suppliers and plant and equipment suppliers. Quotes were obtained from prospective suppliers of aggregate materials. There were nominated suppliers for ready-mix concrete, masonry, cement, reinforcement bars, structural steel sections, and roofing sheets. The suppliers were provided with schedules, and they advised on the availability and logistics plans they had made to ensure the smooth running of the project.

The main contractor (MC) and nominated electrical and mechanical subcontractors were appointed well before the construction process began, and they all provided design input based on their experience with a similar classrooms project by the same client. The construction project manager provided services in identifying preferred aluminium and paint subcontractors. The quantity surveyor was involved from project inception and provided an initial ballpark estimate, concept design stage estimate, scheme design stage elemental estimate, and detailed bills of quantities used for bidding and negotiations with the main contractor.

An integrated mechanical and electrical design consultancy firm was appointed to manage the services part of the contract. They developed designs and estimates used in the main contract.

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Just-in-time: Supply Chain Process

The client worked with over 10 material and equipment suppliers initially appointed through competitive bidding and negotiated contracts. They have supplied material and equipment for a 600 M3 swimming pool with a 320 M^2 changing room, a pump room with associated pumps, water filters, heating pumps, 1250 M^2 paved area and branding. The client has a professional relationship with a wholesale building and civil material supplier, electrical and mechanical supplies, and a ready-mix concrete supplier. Pull planning was used to engage paint suppliers (supply of decorative paints) and aluminium fabricators to supply and install aluminium windows and doors. The successful bidders offered to supply and apply paint. At the same time, the aluminium fabricator was selected for their ability to supply competitive solutions within the time constraints, and an additional scope of aluminium-framed scratch-proof MDF partitions was awarded. The client reduced the time required to build masonry partitions for toilet cubicles using aluminium-framed MDF partitions and doors for toilet enclosures.

The client engaged EPS, tiles and toilet suppliers and was able to secure materials through pull planning so that they were delivered only when required. The orders for EPS panels, roofing cover, and tiles required long lead times to allow special production to fit the design lengths and areas. The specially cut roofing sheets (8.5 M, 6.5 M, 5.6 M, 5.0 M, and 4.0 M long) were procured from a manufacturer in Mombasa and ferried to the site just-in-time for roof cover erection (14 days lead time). Floor tiles were ordered in the required shade and quantity from the tiles manufacturer/ supplier and delivered once the concrete floors had been screeded (6 days lead time). The EPS manufacturer/supplier visited the site and liaised with the structural engineer to produce specially cut 195mm thick EPS panels with ribs for the desired floor spans (5 days lead time).

Supplier engagement and orders were based on identified major milestones, and commitments were secured, leading to the timely construction of the substructures, superstructure frame and walling, roofing, finishes and openings. Payment was made based on firm-up quantities, and the suppliers made deliveries with room for flexibility to defer or fast-track. Stocking materials was kept to 2 days' activities, which saved space requirements and reduced multiple handling. Just-in-time delivery of materials was leveraged so that on days when in situ concrete was planned, cement and aggregates would be delivered early in the morning (before 8:00 am). Where additional materials were required, suppliers had undertaken to deliver within 2 hours of being notified. The accessible locations of the material suppliers allowed for a fast turnaround time for daily material supply.

The ready-mix concrete supplier advised the design team that weekend pours are usually seamless due to improved traffic flow around the site. This proposal allowed the client, construction project manager, and contractor to plan for weekend concreting for the suspended slabs.

Construction Process

The general contractor developed a construction plan and methodology, with the architect's and structural engineer's concurrence, that involved stripping the site to remove vegetable soil before excavating trenches. While determining levels before stripping the site, it was established that there was an average difference in levels of 800 mm over the site, with the lowest point being minus 2200 mm from the reference point (0 mm). The initial structural and architectural designs had assumed a level ground; therefore, the differences in levels necessitated the first change in the structural drawings. The structural engineer introduced a step of 800mm, effectively splitting the plan into two sections (8 classrooms on each split section). This design revision allowed the cost of the foundations to be kept close to the costs at the contract award stage. An access ramp was introduced to allow movement between the lower section of the building and the upper section (on the ground floor).

The client's responsibility was to excavate and reduce levels and ferry away the black cotton to a designated dumping site. The excavation process took 6 days, and 440 M3 was excavated and trucked away. The study employed the Last Planner System approach to streamline the construction of the project. The client, architect, and structural engineer employed concurrent engineering techniques to resolve design issues on site, leading to minimal delay of the construction process.

Lookahead plans were shared with suppliers, who responded accordingly, giving their most optimistic delivery date. Their feedback was used to refine and reorganise site activities without delaying the project. The ready-mix concrete supplier needed firm plans from the site execution team to plan for the batching and delivery of concrete for strip foundations, ground floor slabs, ramps, staircases, floor beams and suspended floor slabs. The look-ahead plan also allowed them to subcontract concrete pumping services to a plant hirer with a concrete boom whose reach exceeds 70M when extended.

Updated requests for quotations (RFQ) were sent to reinforcement steel and formwork suppliers while sharing the project schedule to allow the nominated supplier to plan accordingly and obtain discounts based on volume orders. Pull scheduling informed most of the RFQs, so overstocking was avoided on-site. At the same time, price reductions due to discounts and general material price reduction resulted in marginal (5%) savings compared with the initial costs of the same materials. The method of cost management adopted by the quantity surveyor was weekly valuations of labour-only work and payment made by the client every Friday.

The challenges encountered included aggregates (sand and ballast) weight and /or volume that could not be accurately ascertained because of entrained air. Adjustments had to be made once deliveries were made. It was noted that the average tonnage capacity of sand supply trucks was 10 tonnes, while the ballast supply truck capacity was 12-14 tons. These capacities are regulated by the roads' authority in Kenya to minimise road wear and tear. These limitations resulted in more trucks being ordered, which increased the cost of river sand by 42%, quarry sand by 47%, and 38% for ballast compared with the forecasted cost per tonne (**Table 3**). The case study established these variations in quantities delivered by analysing plans for material (allowance of bulking and waste of 52%) and comparing them to actual work done. Notable cost reduction was 20% and 24% for reinforcement bars and crusher run, respectively.

The main contractor (MC) proposed using ready-mix concrete, which is marginally cheaper than the forecasted cost. Site conditions varied where assumed/provisional substructure quantities and conditions, beginning with levels, varied. This delayed foundation excavations by six (6) days as the MC reduced levels before setting out. Groundwater was encountered, and French drains were introduced as the foundation concreting commenced. This allowed for continuous draining of trenches on the upper sections of the building so that concreting proceeded unimpeded. The lower section of the foundation required a retaining wall due to the approved height (average 2.4m) by the structural engineer. The wall was designed as a masonry double wall reinforced on every course using two runs of 10mm diameter deformed high tensile mild steel bars.

Backfilling and ramming around the foundation areas exceeded the planned time by one (1) week. At the same time, the planned hardcore bed was replaced with a 200mm thick crusher run layer, which reduced the time allocated to hand-packing hardcore material by 4 days. Variations in superstructure walling and suspended slab resulted in marginally higher costs than forecasted initially (7% and 2% respectively). Erection of formwork to support the EPS panels, floor beams, and suspended solid slab took two (2) weeks, during which EPS panels were ordered and delivered to the site. The EPS supplier conducted one (1) day of training, which involved site operatives and their supervisor, and later, an inspection and corrections were done (additional props were recommended).

Last planners (contractor's employees and suppliers) were instrumental in the success of the shell and core phase of construction. Pull scheduling allowed occasional changes to the delivery of ready-mix concrete, cement, reinforcement bars, and fine aggregates. Roofing sheets were an important long lead item that meant working closely with the manufacturer to deliver the correct quantity, in the proper gauge and colour, in 10 days. Notably, these sheets were sourced from a manufacturer located 500km away, and accurate forecasting and streamlined supply management, including delivery, resulted in no delay to the project. Mild steel roofing structure fabrication and erection were scheduled to take two weeks, and the construction project manager worked with the supplier to realise just-in-time delivery of roofing sheets.

There was a lapse in activity coordination between plasterwork and aluminium windows, with a 10-40mm margin of error. This necessitated hacking the plaster to fit the windows. The last planner (aluminium fabricator) proposed using mild steel

TABLE 3
Analysis of Bulk Material Cost – Planned vs Actual Cost

	Material	Unit of Measurement (UoM)	Forecasted cost (per tonne in US$)	Actual Cost (per tonne in US$)	Percent increase in price
1	River Sand	Tonne	16.96	24	42%
2	Ballast	Tonne	14.24	19.60	38%
3	Quarry Sand	Tonne	13.36	19.60	47%
4	Concrete	CM	124	122.40	-1%
5	Reinforcement bars	Kg	1.68	1.34	-20%
6	Crusher run	Tonne	18	13.71	-24%

Source: Kioko, Masu & Rukwaro, 2025

templates in phase two (2) to confirm opening sizes. The masons and plasterers used customised templates in phase 2 to eliminate the time and material wastage noted in phase 1. Delays were eliminated, and window installation proceeded without rework and wastage.

Plasterwork to the soffit of EPS panels proved to be a challenge to the team on site, and the application of roughcast plaster and final coat had to be varied (2 separate days). There were abortive works for 25% of the area as the plaster kept falling off the soffits. This resulted in claims for additional payment for labour and a significant increase in the thickness of the soffits (average 40mm from the design thickness of 15mm). The EPS supplier engaged the main contractor (MC) in phase 2 and plaster methodology (reduced water ratio and improved cement content), which resulted in fast, efficient soffit finishes.

The project was implemented during school hours, and the work methodology involved directing bulk transport of concrete and aggregates very early in the morning or late in the evening and on weekends. The site has three access and exit points, which ensured that there was a designated route for all site operations.

A nominated subcontractor (manufacturer, supply, and installation) carried out the scheduling, surface preparation, and painting of ceilings, as well as internal and external walling. The MC handed over plastered classrooms in batches of 4 classrooms per week, according to an agreed-upon weekly plan. The phased release of classrooms allowed the MC to return to laying floor tiles after the scheming and painting of undercoats to ceiling and wall surfaces was complete.

The SE's proposal to use marine ply formwork on all solid slab sections resulted in smooth, even soffits. This eliminated the need to plaster the surfaces and fast-tracked the preparation and painting of these areas (1200 M2). The initial cost of the forms was high, but the omission of plaster work and the consistency in surface finish mean reduced cost in the maintenance phase whenever repainting is required.

The contractors' employees worked extra shifts (8-hour night shifts) to meet the project's time plan, and additional gangs were employed to fast-track urgent walling and plaster works to meet the weekly handover plans. The project was completed by week 14 (phase 1) and week 10 (phase 2), and prospective parents could access completed classrooms during an open-day event organised by the school administration. The classrooms, washrooms, dining hall, and retrofitting of an existing building were implemented concurrently to meet the project's time constraints.

The case study identified several waste contributing activities as detailed in **Table 4**.

The last planner system (LPS) was implemented for 24 weeks, and tables were used to capture inputs (feedback) from site operatives. The architect's office was 300M away, while the structural engineer's office was 2 km away, and this proximity played a considerable role in the scheduling of activities as the project progressed. Any discrepancies in design were addressed in real-time, and conflicts were resolved as soon as the last planners raised queries. The construction project manager would contact the designers and seek additional information or instructions, leading to 83% of the planned activities being completed as planned each week (**Tables 5** and **6** on the next page). This study tracked the planned cost against the actual cost for reinforcement bars and aggregates, with savings of 20% and 24%, respectively (**Table 3**).

Some predetermined root causes for missed commitments are:

- Weather (rains in June 2024, July 2024, and November 2024);
- Inadequate manpower by the main contractor;
- Machinery breakdown;
- Design changes;
- Fabrication of windows and doors, and CNC Panels;
- Special dimension materials being sourced far away (89km to 550km away);
- Poor scheduling by subcontractors, resulting in conflicts and remedial works after plastering was already done

DISCUSSION

There are opportunities to implement lean construction tools more than once, as this case study has demonstrated. Fiallo and Revelo (2002) noted the importance of having lookahead plans

TABLE 4
Summary of waste contributing activities on site

	Construction Phase		Supply Chain
1	Coordination between MC and nominated subcontractors needed external intervention. PM coordinated the activities of the services subcontractors to ensure their first fix activities did not delay the MC's plan	1	Orders were delayed by up to 6 hours, and certain suppliers required the client to have account profiles established in their Enterprise Resource Management (ERM) systems (with a minimum order quantity per month). The registration process to open accounts for purchasing was cumbersome, and PM advised the client to use existing resellers/distributors with active accounts to purchase and process the project orders.
2	Occasional wastage through batching excess mortar or plaster a few hours before the day shift ends. MC directed his staff to ensure that the batching of mortar/plaster matched their productivity of 1-2 M2 per hour. Where plaster/ mortar material fell on the ground, the unskilled labour personnel would collect and re-batch with fresh batches.	2	The unavailability of the selected shade of additional tiles after payment led to a change in the desired shade and additional transport costs from the manufacturer's factory, which is 80km away. This also necessitated a change in the tile layout plan by the architect. The solution was to order all materials after the designs were locked (phase 2). The advantage is that the supplier provides free transport for bulk orders (10 tonnes and above)
3	Breakage of conduits and blocking of plumbing pipework. The services subcontractor staff were present during the concrete pour to ensure plugs on all plumbing points and conduits were not damaged or moved. A few conduits had taken in concrete after the plugs came off during the vibration of the concrete	3	Offloading costs were overlooked when estimating the cost of materials because certain suppliers had their staff offload. At the same time, other suppliers would only send their drivers with the materials ordered by the client.

Source: Kioko, Masu & Rukwaro, 2025

TABLE 5
Phase 1: Planned vs Implemented Activities (June – August 2024)

	Activities														Average
Activity Planned (Lookahead Plans)	5	8	9	8	6	13	11	9	15	14	25	12	11	14	
Activity Completed	3	6	7	7	5	11	9	7	14	12	22	10	9	13	
	60%	75%	78%	88%	83%	85%	82%	78%	93%	86%	88%	83%	82%	93%	82%

Source: Field survey, 2025

in their case study on applying LPS on a housing project in Ecuador. There was a 30% reduction in PPC when there was no lookahead programme (week 5), while on the other hand, there was a 14% increase in PPC when lookahead plans were incorporated. The application of the last planner system indicated a modest 64% PPC in Ecuador (Fiallo & Revelo, 2002) and improved 89% PPC in Egypt (Issa, 2013). The current case study noted a PPC of 83% (**Table 6**), and the PPC improved

TABLE 6
Phase 2 Planned vs Implemented Activities (November – December 2024)

	Activities											Average
Activity Planned (Lookahead Plans)	3	4	6	5	5	6	6	5	6	9	10	
Activity Completed	3	3	4	5	4	4	5	4	5	8	9	
	100%	75%	67%	100%	80%	67%	83%	80%	83%	89%	90%	

Source: Field survey, 2025

as the project progressed from phase 1 to phase 2. This is attributed to adequate labour for various tasks, earlier engagement with suppliers, and adjusting the project schedule to match nominated suppliers' and contractors' timelines.

Concurrent engineering was utilised during construction to adapt the structural design when site levels proved challenging. The level reduction was implemented the same day after the structural engineer's instructions. The revised structural drawings were sent three (3) days later, when casting of strip foundations was already underway. A last planner (main contractor) proposed the other opportunity for concurrent engineering after they encountered a hollow block wall on site instead of a solid load-bearing wall. The main contractor proposed modifying the structural engineer's design to have chemical anchors to receive bearing end plates of a universal beam (UB). The hollow block wall would not be able to provide the anchorage required to support the beam. The proposal adopted involved having structural steel square hollow sections (100x100x4 mm thick) as columns with base plates supported by new concrete stub columns.

The structural engineer used concurrent engineering concepts to implement a double-walled natural stone retaining wall reinforced with two (2) runs of 10mm diameter ribbed bars on every course. This eliminated the need to use a 300mm thick reinforced concrete retaining wall, whose cost was higher. French drains were incorporated into the retaining wall design because that section of the plan was the lowest point on the site, and groundwater was visible after excavation. The client, who is also an architect (design manager), modified the design of the dining hall to accommodate a fruit tree on site by designing the roof to have an opening for the tree stem to pass through.

CONCLUSION AND RECOMMENDATIONS

This study's main objective was to evaluate the applicability of planning and scheduling tools in design and construction through the application of the Last Planner System (LPS) and Concurrent Engineering (CE). The findings validate the assumption that lean construction tools can be deployed to address cost overruns, delays and poor quality in a classrooms' construction project through lean design planning (pre-construction phase) and lean construction management (construction phase). The significance of breaking the project schedule into weekly plans was underscored in the case study, with an 83% PPC achieved over the project's life. The upward trend of the PPC as time progressed (**Figures 4** and **5**) indicates organisational learning, which should be considered when applying lean design and construction tools.

Active management of variability of the design and construction processes is key to implementing lean construction tools. There is an opportunity to use lean construction tools to manage cost overruns, minimise delays and achieve quality targets at a lower cost. The case study recommends active management of challenges encountered in LPS implementation and training carried out throughout the project life to realise the benefits of these lean design and construction tools. Lack of training and resistance to change were noted as challenges to LPS implementation (Porwal et. Al., 2010), and these were addressed through timely training and follow-up to ensure that lookahead plans are realistic and activities are tracked to completion.

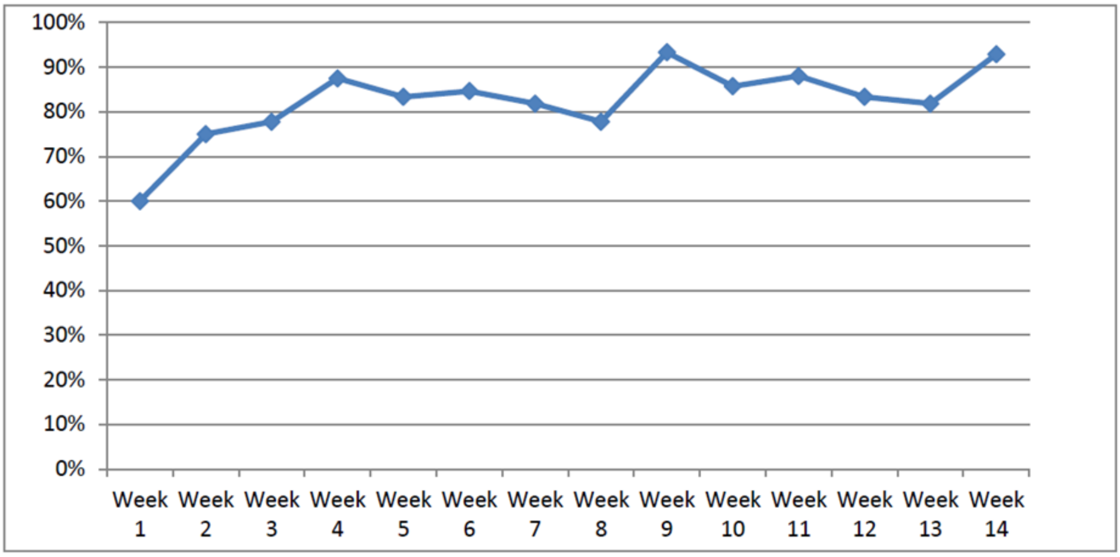

FIGURE 4
Percent Plan Complete: Average completion of 82% in Phase 1
(Time: June 2024 to August 2024).
Source: Field survey, 2025

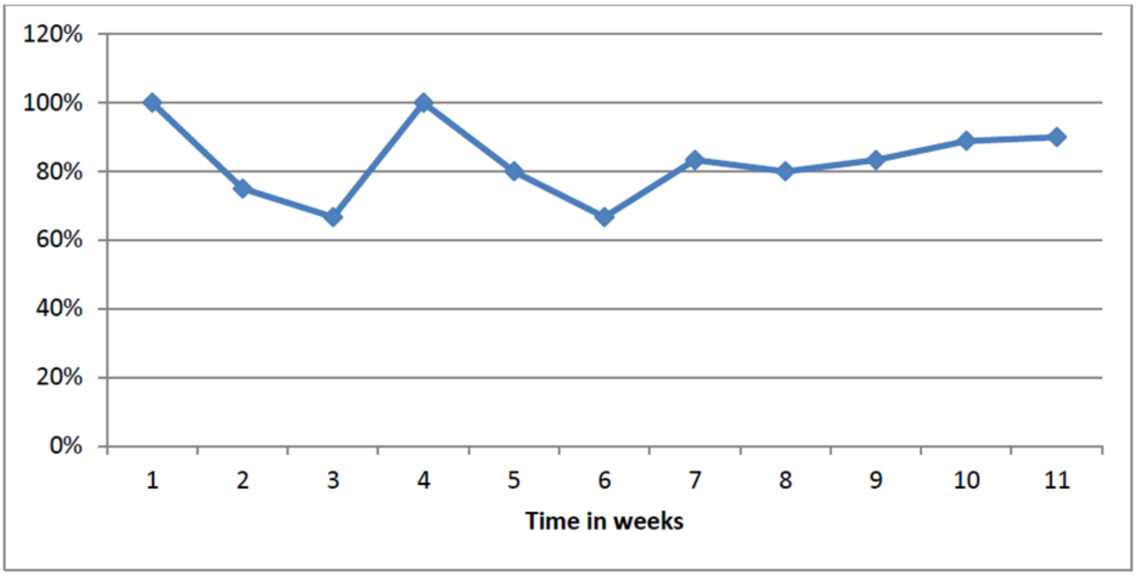

FIGURE 5
Percent Plan Complete: Average completion of 83% in Phase 2
Time: November 2024 to December 2024
Source: Field survey, 2025

The study proposed a collaborative framework for integrating LPS with CE, in which information in the correct quantity and time was deemed essential in the output/approval given by architects, structural engineers, and electrical and mechanical engineers. **Figure 6** illustrates the iteration processes and the communication feedback loop that are essential for control and achieving seamless results.

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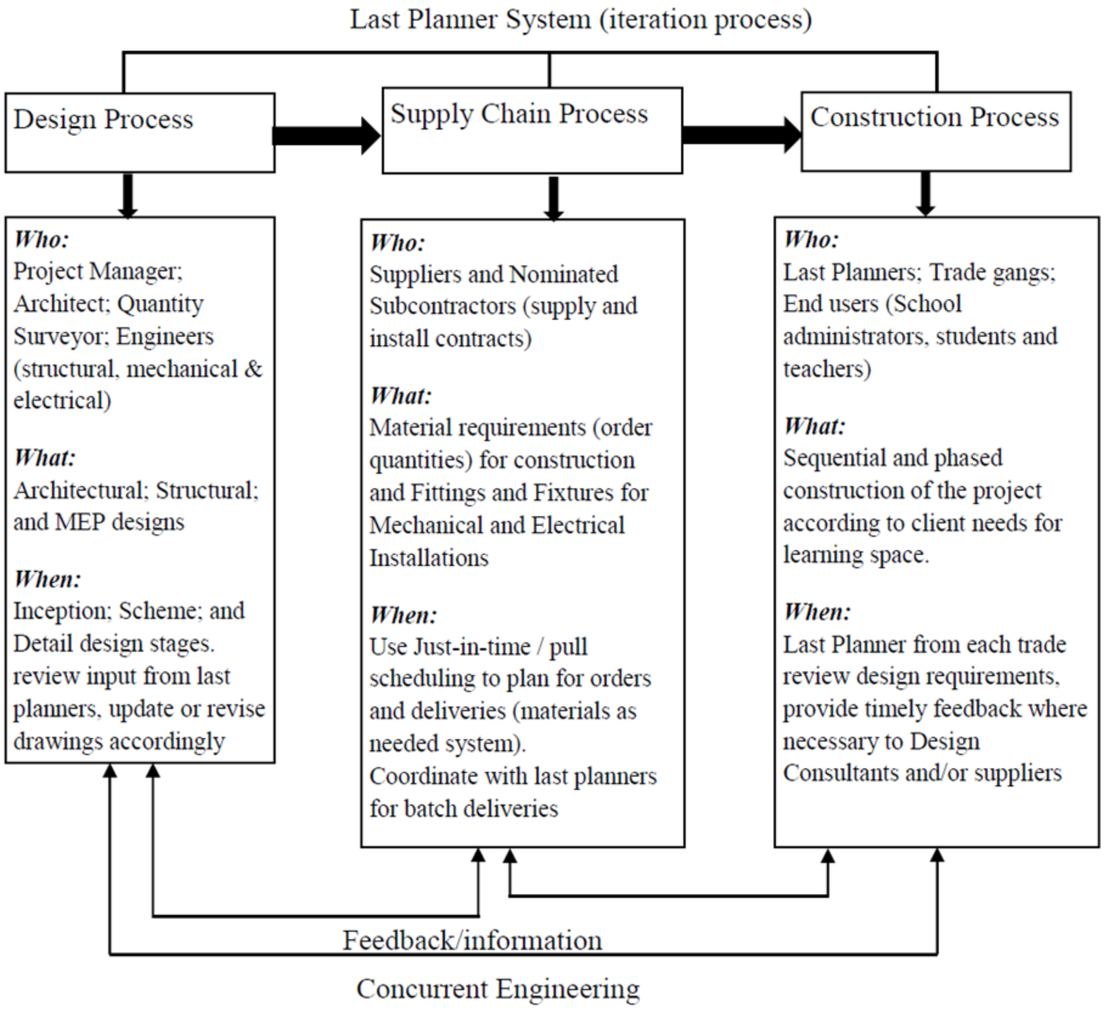

FIGURE 6
Proposed Framework for integrating Last Planner System (LPS) with Concurrent Engineering (CE)
Source: Field survey, 2025

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