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Visual Lean planning tools in the construction industry: A Norwegian case study

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Abstract. Despite being the world's most significant contributor to the global Gross Domestic Product, the construction industry has untapped potential in its productivity, with frequent project delays and conflicts. Thus, a growing number of contractors implement visual Lean tools, such as the Last Planner® System (LPS). The paper explores the essential visual Lean planning elements to increase the cohesion between planning and production in construction projects through a project case study and lessons learned in the industry. The research indicates that look-ahead plans, soundness checks, early phase planning, BIM models, and applying visual Lean planning in both the design and production phases are critical success factors when using the LPS.

Keywords: Visual planning boards, Lean construction, Last Planner System, Visual Lean planning

Introduction

Although the construction industry displays a steady growth rate, it also has one of the lowest overall increases in productivity, at one percent globally, during the last twenty years (Ribheirinho et al., 2020). SINTEF, 2020, identified low productivity and not completing the time and financial requirements as the most significant construction challenges. A study by KPMG, conducted in 2015, found that three out of four construction projects globally do not meet their assigned deadline. One way to improve productivity in the sector is through implementing visual Lean planning tools to bridge the gap between planning and production.

As urbanization increases, the pressure on cities' dynamics creates a challenging environment for managing construction projects. Further, project timeframes are shorter, contracts more elaborate, and environmental requirements stringent. Thus, the context for a construction project in a large city like Oslo, Norway, is demanding. As a result, the traditional ways of carrying out a construction project are outdated. Despite technological advances and new management methodologies making their way into many industries, the construction industry lags behind. Nonetheless, the long traditions of handcraft, expertise and specialist knowledge in the field provide a great starting point for this industry to contribute to the global economy significantly. The precondition, however, is that the effectiveness of its processes is improved.

The adoption of methods like Lean Engineering is increasing in popularity. Lean Engineering has proven to increase productivity and value creation through its emergence in the Japanese production of cars. It is a holistic approach to removing waste in production based on five main principles,

defined by Womack and Jones, 1996. The principles include *identifying value for the customer, identifying the value stream, creating flow in the process, letting the customer pull value, and continuous learning*.

An increasing number of contractors in the construction industry have begun integrating Lean principles in their projects using visual Lean planning methods to complement traditional scheduling tools. Typical tools include Gantt charts, Program Evaluation Review Technique (PERT) diagrams, and the Critical Path Method (CPM). The Last Planner® System (LPS) for Production Control is a Lean production control system first presented by Ballard in 1993. The LPS is composed of five levels of planning and enables a reliable workflow. The LPS fosters teamwork, problem-solving, and commitment to the plan (Jurado, 2012). The result is a dynamic plan, which provides a more realistic reflection of the project's status and encourages continuous learning. Ultimately, contractors who employ visual Lean tools, such as LPS, gain a competitive advantage in a complex context, where value creation is vital to survival.

The paper aims to investigate how to successfully implement visual Lean planning tools in a Norwegian construction project to increase the cohesion between planning and production. The research presents a case study of a renovation project in Oslo's city center, referred to as KA23, built by SELTOR. The following section outlines the research methodology and its limitations. After that, the paper presents theoretical background on the visual Lean planning method, followed by exploring the established LPS methodologies of three significant contractors operating in the Norwegian construction industry. Then, the paper presents a case study of LPS applied to the KA23, supported by data collected from the project. Finally, based on SELTOR's and the other contractors' practices, the paper collates the lessons learned.

Research methodology

The research aims to determine how a contractor in the Norwegian construction industry can implement visual Lean planning tools to create cohesion between planning and production. The study includes empirical research over 29 weeks. The objectives of the study were to determine:

1. What is visual Lean planning?
2. How have Norwegian contractors applied visual Lean planning?
3. What are the lessons learned from using the LPS in the KA23?
4. Which visual Lean planning processes improve the cohesion between planning and production?

Data collection

Qualitative data collection. The qualitative data were collected both internally from the KA23 as well as from external sources. Firstly, the study of the KA23 involved observing visual Lean planning in practice by collecting informal feedback from the subcontractors and SELTOR team during the collaborative planning sessions and daily plan checks. The notes were used as learning points to improve the LPS process further. This type of action research (Parkin, 2009) is suitable in a Lean context as it entails using the study's reflections to implement change continuously. The benefit is that the research has practical value and contributes to its learning process as improvements occur quickly. However, action research makes it challenging to maintain an objective perspective as the researcher is directly involved in both the research and the project. Further, an external researcher would have removed the bias introduced by a SELTOR employee conducting the research.

The final stage of the qualitative data collection was the interview section. The interviews were the last part because pre-existing knowledge of the LPS was necessary to create interview questions with sufficient depth. The subjects of the semi-structured interviews were three large contractors operating in Norway country and the client of the KA23. The chosen contractors are suitable interview subjects because they fulfill an equivalent project role to that of SELTOR. Further, these contractors have established a well-defined practice using visual Lean tools due to many years of experience. Semi-

structured interviews enable the researcher to control the response environment and the order of discussion points while still allowing room for additional topics and in-depth explanations. The transcriptions of the interviews provide a comparative overview of the methods employed by the different contractors. Finally, the KA23 client provided input on their expectations and experiences on the project during a semi-structured interview. The interview results outlined how the contractor could have improved the visual Lean planning from the client's perspective. Conducting interviews with internal and external parties to the contractor and KA23 provided a holistic perspective for balanced conclusions.

Quantitative data collection. The Quantitative data involved tracking the weekly plan activities during the daily plan checks for 29 weeks. A project-tailored Excel sheet determined the daily Percent Plan Complete (PPC), a measure of commitment accuracy, using daily plan check data. The data collected during daily plan checks included the number of activities on plan and the number of activities completed. The same sheet recoded the Reasons for Missed Commitment (RMCs) to identify weekly and overall trends of incomplete activities. SELTOR communicated the weekly PPC and RMC statistics using graphical models to foster learning from experience. The data collection involved manually counting post-its on the planning boards. The manual counting method introduces inaccuracy due to human error and practical issues, such as post-its falling off. As a counter-measure, the data was collected over many weeks to create a more extensive data set. Further, there is a degree of subjectivity involved in the root-cause analysis used to identify the RMC as it depends on the respondent's perceptions. Although this makes the data less accurate, it is a suitable analysis method as it follows the LPS methodology.

Visual Lean planning theory

Lean construction has its origin from the Toyota Production System, implemented in Japan's automotive industry after the Second World War (Jones et al., 1999). Lean in construction aims to improve project delivery and increase perceived value for the customer. Many contractors have begun implementing Lean principles by removing wasteful activities from their management processes, such as in the planning phase. The LPS is a Visual Lean planning tool tailored to the construction industry based on Lean principles. The goal is to create a system that achieves planned activities and determines alternative paths to take when that is impossible. LPS is applicable through the entire lifecycle of a construction project, including but not limited to the development, procurement, design, and construction phases. Visual Lean planning aims to create a workflow that achieves reliable execution by using the pull technique to plan at the downstream customer's request (Lean Construction Institute, 2017). Pull planning entails working from the target completion date backward instead of traditionally planning forward. The milestones, therefore, set the boundaries for the planning.

Visual Lean planning occurs in an *Obeya* room, either physical or digital. The space provides all relevant information needed to plan and monitor the project's progress, such as the project plans, zone diagrams, and plan drawings. During collaborative sessions, the subcontractors place physical or digital post-its on the planning boards of the Obeya room to create plans at different hierarchical and detail levels. Thus, instead of the contractor's Site Manager creating and owning the master plan, the subcontractors are visibly accountable for their plan activities. The five-level hierarchy LPS shown in Figure 1 involves planning what *should*, *can*, and *will* be done and evaluating what *did* get done. The *learning* points are also a significant part of the system (Lean Construction Institute, 2017).



Figure 1. The Last Planner® System (Lean Construction Institute, 2017)

Like in the CPM developed by Kelley and Walker in 1959, a master schedule for the entire project duration is created in the LPS. The team employs the pull technique to identify the milestones, legally binding commitments. Based on the master plan, subcontractors collaboratively create Phase plans to schedule the workflow and hand-offs between disciplines. The number of phase plans depends on the project, as it involves planning different parts or phases of the project, such as groundworks, base structure, and the like. Make-ready planning involves creating a look-ahead plan for a window of six to eight weeks and identifying constraints to the phase plan's upcoming activities (Ballard, 1993). Many contractors check the *soundness* of activities before releasing them to the next stage of planning. Checking for soundness refers to ensuring that the preconditions are in place for the activities to commence. The preconditions vary from contractor to contractor but typically include *engineering/drawings, information, space, materials, preceding activity, workforce, environment, and health and safety*. Should preconditions not be in place, the team creates specific activities to complete them. Once the team ensures prerequisites are ready, the activities commence. Weekly work planning details the daily tasks for the upcoming one to two weeks.

LPS aims to create a culture that fosters learning at every stage. The team participates in daily plan checks and makes adjustments to stay on plan; thus, the plan is a dynamic document rather than static, as is often the case in traditional planning. Further, monitoring the weekly PPC indicates how accurately the plan reflects future events. PPC is measured by dividing the number of completed activities by the number of activities on the plan. During daily plan checks, the team places incomplete activities into an RMC category by running a 5 *Why's* analysis, asking *why* five times to trace the actual root cause. The RMC categories reflect the categories for soundness checking in the project. Reoccurring issues are identified and managed in the project to avoid further occurrence.

Visual Lean planning in the Norwegian construction industry

Construction is the second-largest Norwegian industry, with 25% of the country's workforce (SINTEF, 2020). The construction industry operates in a project-based manner, with compartmentalized production units that act as separate entities. Despite every project being unique, there are many commonalities between them. Therefore, there is excellent potential for industry-wide improvement by making use of the knowledge gained during projects. Many construction companies currently have inadequate processes to manage knowledge acquired by the transient project teams. The result is that the same mistakes are repeated and "the wheel being reinvented" time after time.

Furthermore, SINTEF, one of Europe's largest independent research institutes, concluded that the construction industry was the second lowest out of 45 in its innovation degree. SINTEF linked this to the fact that 70% of the companies in Norway's construction industry have less than 50 employees. Thus, many of these companies do not have the necessary resources to restructure and innovate. A large portion of the workforce in the Norwegian construction industry is foreign. Eastern-European countries like Poland and Lithuania represent the largest immigrant groups nationally and on construction sites (SSB, 2021). Cultural differences, language barriers, and risk adversity in the culture create a challenging environment for change.

External disruptions, like the Covid-19 pandemic, expose the vulnerabilities in the construction industry. Such vulnerabilities include low overall technical innovation, many foreign workers, and a lack of knowledge transfer processes. A disruption like a pandemic creates an opportunity and incentive for change. The industry must find a "new normal" that aligns with its strategic vision to compete in an increasingly challenging market. Thus, new approaches are slowly starting to permeate the industry, such as Industry 4.0 technology and new project management methods.

Lean applied by Norwegian contractors

The following section displays the main differences between the methods of the interviewees and SELTOR. Table 1 provides an overview of the contractors interviewed.

Table 1. Interview subject profiles

CONTRACTOR	1	2	3	SELTOR
Number of employees	33 500	1000	8000	150
Project size range	70 – 3000 MNOK	9 – 1000 MNOK	80 – 2400 MNOK	6 – 400 MNOK
Project types	Buildings and Infrastructure	Buildings	Building and Infrastructure	Buildings

Introducing Lean in projects. Two out of the three contractors reported using internal resources as transient consultants who leave the project team once confident using Lean. Contractor 2, like SELTOR, uses project staff with Lean experience. Although the latter is also an effective method, it ties necessary project resources to managing Lean in the initial project phase. Further, a resource external to the project team may add an unbiased perspective to the Lean processes in the project.

Lean in the design phase. All three contractors interviewed apply visual Lean tools in the design phase by integrating the procurement plan, client decision plan, and engineering plan in an overall visual Lean engineering plan. The milestones are engineering deliverables that align with the production milestones to increase the coherence between engineering and production.

Daily plan checks. Only Contractor 3 uses daily plan checks, like SELTOR. The other contractors are reasoning that the subcontractors already attend many weekly meetings. Further, the contractors interviewed use digital tools that enable foremen to check out activities immediately through a phone application when completed. Contractor 3 and SELTOR use daily plan checks, short 10-15 minute standing meetings to ensure that the activities for the day are feasible. Additionally, the contractors that use daily plan checks collect daily PPC and RMC data to monitor the progress closely.

Lean week plan. The contractors interviewed structure their week plans according to zones. However, this requires significant wall space or digital tools, as plans tend to become very large when separated by zones. The benefit of structuring by zones is a more precise visualization of the dependencies between activities and other disciplines working in the same zones.

Lean master plan. All contractors interviewed use Microsoft Office (MS) Project scheduling tools as the basis for the master plan. Contractor 2 does not make a visual Lean master plan but uses the MS project master plan as a basis for further planning.

Look-ahead plan. The contractors deemed look-ahead planning a vital plan that connects the master and phase plans to the week plan to ensure activities are made ready for the next planning level.

Phase plans. All three interview subjects placed importance on using phase plans from early on in the project. Phase planning is an essential part of the Lean planning methodology that ensures that the hand-offs between disciplines and activities are feasible. Contractor 3 uses phase plans in the design phase with the same phases as production to ensure a correlation between the plan levels. Further, some activities require early planning, such as building elevators, which have long delivery lead times, require ample space, and include many interfaces.

Soundness check. All three contractors conduct a soundness check before moving activities to the next planning level. The categories vary but align with the respective contractor's RMC categories. The contractors conduct Root Cause Analyses to diminish the underlying causes for obstructions to work and create a culture of learning and prevention.

Metrics. Like SELTOR, the contractors interviewed monitor the planning through PPC and RMC. Contractor 2 also measures the Percent Plan Expected and the Percent Plan Prepared. Although the latter two metrics may be interesting, the PPC and RMC are sufficient to implement learning in the project and monitor the planning accuracy.

Health and Safety, and Logistics. The contractors include Health and Safety (H&S) in their plans to a greater degree than SELTOR has done. The three contractors integrate H&S as a significant part of the progress planning and visualize it as separate activities, such as *Safe Job Analyses*, logistically complex operations, and hazardous activities.

Client involvement. All three contractors identified client involvement as an essential part of the collaborative approach. Contractor 2 uses the client's decision-making plan to create milestones for the Lean engineering plan. A reoccurring problem in construction projects is the lack of client decisions. As most client specifications, particularly for renovation projects, leave room for options and specifications during the projects, client decisions become closely related to project progress.

Digital versus physical phase plans. All three contractors use a combination of digital and physical post-it plans, giving the project team flexibility to choose the preferred method. Using digital planning boards was particularly useful during the pandemic, as the team was not reliant on physical presence to create and monitor plans. As a result, several contractors introduced digital planning to a higher degree during the pandemic due to restrictions in the number of people allowed in the same room.

BIM. All the interview subjects identified the Building Information Model (BIM), a walkable virtual 3D model of the building, as an essential project tool. It enables efficient problem solving during meetings and decreases design errors and rework. BIM desks act as on-site meeting arenas, where the workers can resolve obstructions challenges to the work.

Case study: The KA23 PROJECT

The KA23 is the renovation of a 9-story office building in the heart of Oslo city based on a *Design and Build contract* with an approximate building time of 12 months. *Design and Build* contracts imply that the contractor is responsible for the engineering design and the production (Standard Norge, 2011). KA23 is a FutureBuilt project, a portfolio of projects that achieve the lowest possible greenhouse gas emissions. The building's renovation aims to reuse at least 50 percent of materials to satisfy the FutureBuilt requirement for *circular economy buildings* (FutureBuilt, 2020). In addition to this, the façade is of historical value, there is no space for storage, and the building lies on the corner of two highly trafficked roads with no parking space. Figure 2 shows the situational diagram of KA23 with an overview of the logistics system, Myloc, that SELTOR managed on the project.

The building location creates a complex logistical context as the traffic authorities have only approved closing the road for 4 hours, two nights per week. The logistics on KA23 differ from usual projects because subcontractors do not transport their materials to the site and instead book a delivery slot. KA23 follows the Lean *Just-in-Time (JIT)* principle, which means that supplies are delivered to specified zones to cover only a short production period. JIT avoids an overfilled construction site with obstructions of supplies due to low storage capacity and reduces the project's carbon footprint.

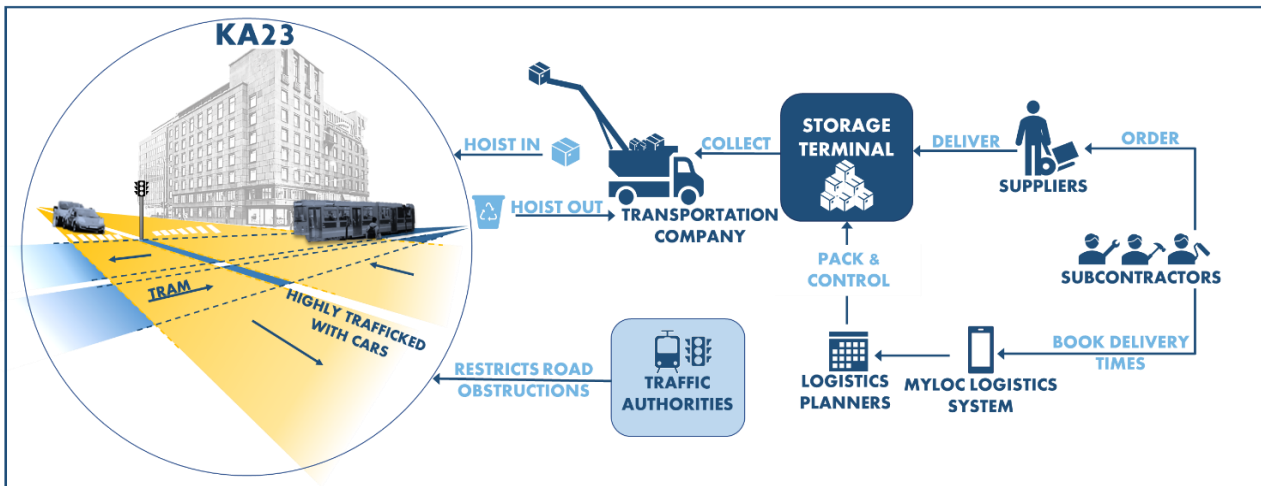


Figure 2. Situational diagram of the KA23 location

At the terminal, the logistics team organizes the supplies according to the calendar's bookings using the Myloc Logistics system. Products are stored at the terminal for a short period before the transportation team hoists them into the building. According to their labels, the transportation company then places the supplies in their assigned storage location in the building. During the same operation, the lift hoists waste out. The central element of the KA23 construction site was the *management room*, used to plan and monitor the project's progress, shown in Figure 3.

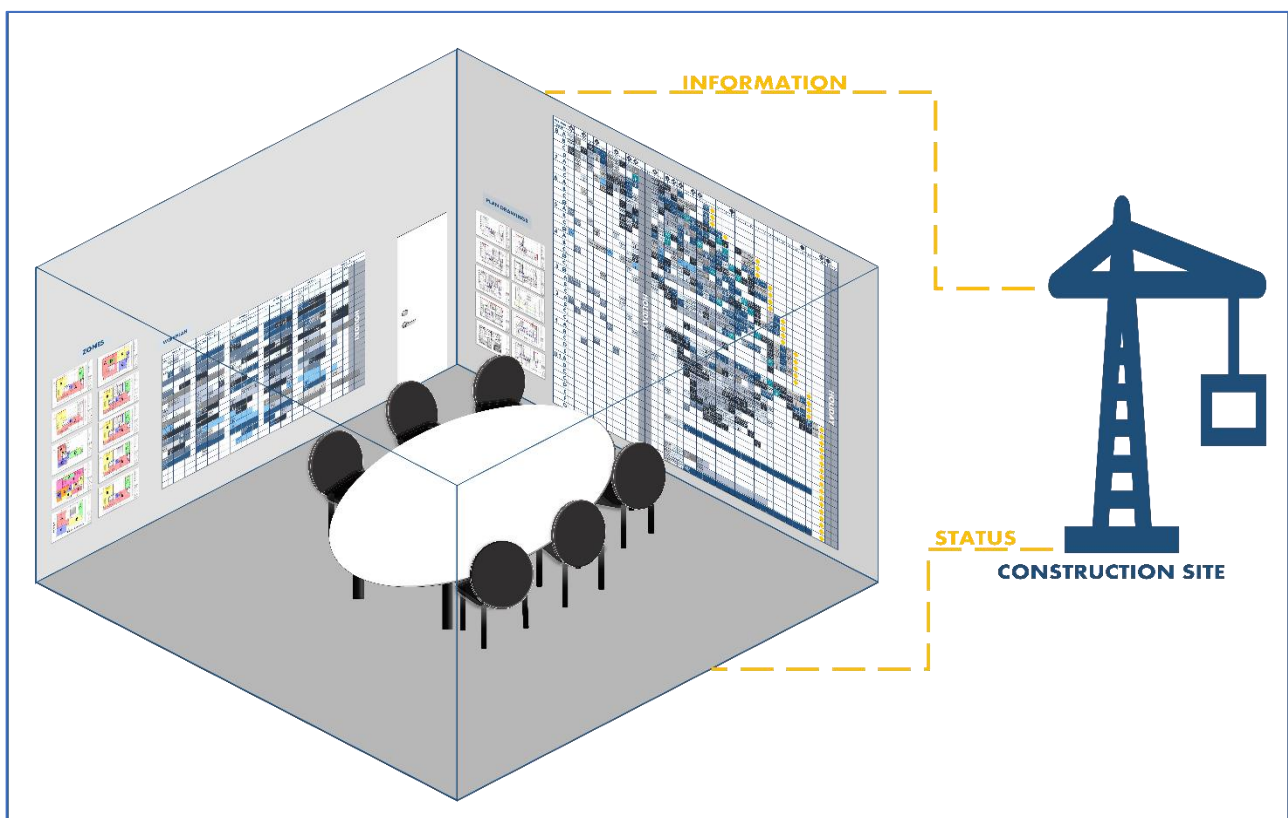


Figure 3. The KA23 management room

The management room housed the master, week, and phase plans, zone diagrams, engineering deliverable plans, and floor plans. Additionally, the room included the BIM, which was also available to the project members off-site and through a BIM desk on the construction site. The room's purpose was to provide relevant information and foster collaborative problem-solving. Thus, the content was tailored and updated to meet the needs of the project. The challenge of having an Obeya room on site

is that at some point, the room will most likely conflict with the construction's progress. At KA23, the room was demolished and set up in a different location midway.

The contractor team tailored the meeting structure of the project to complement and optimize the Lean process. An essential part of making the Lean meeting structure function is to have a session owner for each meeting level. It is also vital to invite the right participants, including a meeting owner and facilitator, to manage the agenda, note the Minutes of Meeting, and encourage discussion. It also includes a decision-maker with authority to make decisions to keep progress. Besides the meetings, the assistant PM facilitated Lean planning sessions. Figure 4 shows the KA23 meeting structure.












EXTERNAL ATTENDEE	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	SELTOR OWNER
 FOREMAN	DAILY PLAN CHECK	DAILY PLAN CHECK	DAILY PLAN CHECK	DAILY PLAN CHECK	 SITE MANAGER
 FOREMAN	H&S ROUNDS		FOREMEN MEETING	LOGISTICS MEETING	 SITE MANAGER
  PROJECT MANAGER FOREMAN				PROGRESS MEETING	 SITE MANAGER
 PROJECT MANAGER			TECHNICAL MEETING		 ENGINEERING MANAGER
 CLIENT				CLIENT MEETING	 PROJECT MANAGER

Figure 4. The KA23 meeting structure

Legally binding the project participants to use Lean planning and adhering to the project's principles through integrating Lean in the contracts was a vital first step. Using Lean tools in a construction project entails more than simply introducing post-it plans or digital planning boards. Firstly, it is essential to create a culture that fosters cooperation and involvement. Hosting onboarding sessions or kick-off events is how many contractors, including SELTOR, are introducing Lean to their project teams. The client, KA23 team, and subcontractors attended an onboarding session with an external Lean consultant and the assistant project manager (PM), a SELTOR employee with Lean experience. The onboarding aimed to make the project participants understand *why* to use Lean. The sessions were a crucial step in the process, emphasized by the positive attendee feedback.

The KA23 plan hierarchy

Through collaborative planning sessions, the top-down approach to planning, which means that management creates a plan and the employees follow, was complemented by a bottom-up approach. The bottom-up approach entails the on-site workforce planning and managing their work, thus creating accountability. Figure 5 illustrates the KA23 plan hierarchy.

LPS allows PMs to level production and manage the flow of input in the project. Most activities have a degree of "float" in their activities, enabling workers to start later and regulate the workforce, deliveries, and materials. As long as critical path activities are not affected, some deviation from the plan is accepted. The subcontractors agreed on a pace of production based on the milestones during the planning sessions based on what would be efficient production for all disciplines. Figure 6 provides details of the production plans used at KA23.

Further, KA23 defined an optimal post-it format for physical planning boards. Figure 7 shows the post-it format that effectively communicates the activity's zone, parameters, and status.

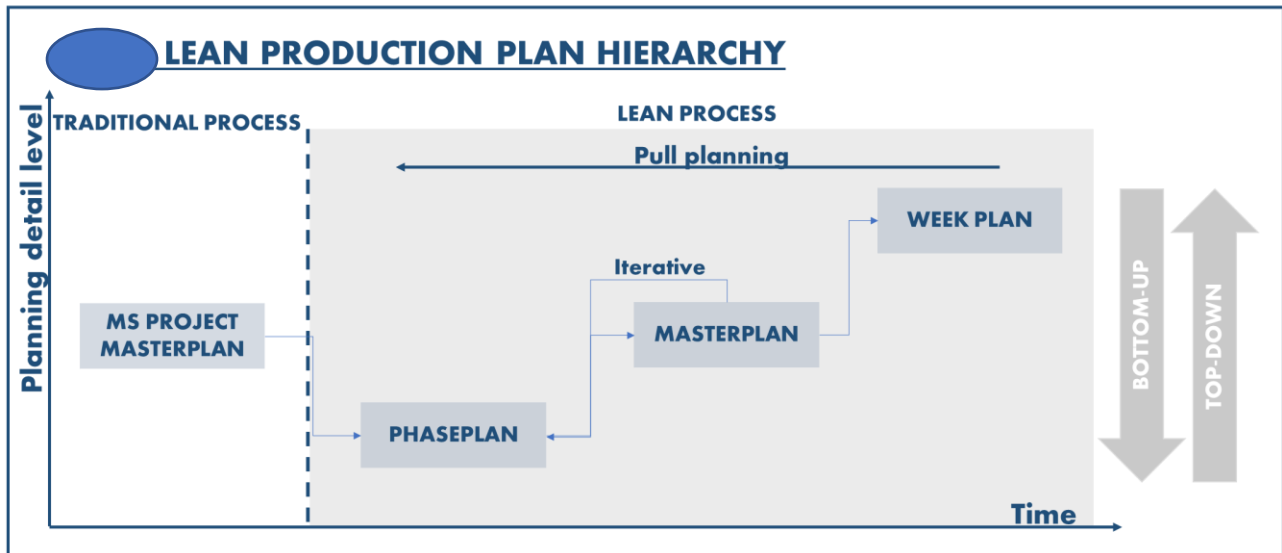


Figure 5. The KA23 plan hierarchy

	LEAN PRODUCTION PLANS			
	MS PROJECT MASTERPLAN	PHASEPLAN	MASTERPLAN	WEEK PLAN
FUNCTION	SET MILESTONES, GUIDE OVERALL PRODUCTION, LEGALLY BINDING	FIND THE FLOW, DEPENDENCIES AND SEQUENCE OF ACTIVITIES	SHOW MILESTONES, PLAN THE WEEKLY ACTIVITIES AND COORDINATE DEPENDENCIES	PLAN THE DAILY ACTIVITIES AND VISUALIZE DEPENDENCIES
CREATED BY	ASSISTANT PROJECT MANAGER	SUBCONTRACTORS (PROJECT MANAGERS & FOREMEN)	SUBCONTRACTORS (PROJECT MANAGERS & FOREMEN)	SUBCONTRACTORS (FOREMEN)
CREATION TIME	BEFORE PRODUCTION STARTS	WHEN PRODUCTION IS PLANNED	WHEN PRODUCTION IS PLANNED	EVERY THREE WEEKS
UPDATED	WHEN BIG CHANGES TO PLAN OCCUR	WHEN REPLANNING ACTIVITIES	WHEN MAIN ACTIVITIES ARE COMPROMIZED OR REPLANNED	WEDNESDAY FOREMEN MEETINGS
CHECKED	WHEN CHANGES TO PLAN OCCUR	WHEN REPLANNING ACTIVITIES	THURSDAY PROGRESS MEETINGS	DAILY PLAN CHECKS (MON-THURS) MONITORED BY PERCENT PLAN COMPLETE AND DEVIATION TRACKER
PLAN OUTLOOK	ENTIRE PROJECT LIFECYCLE (12 MONTHS)	SPECIFIC PHASES (3-9 MONTHS)	ENTIRE PROJECT LIFECYCLE (12 MONTHS)	3-6 WEEKS

Figure 6. The KA23 production plans



Figure 7. The optimal post-it format

The phase plan. Phase plans are theoretically created one to two months before the phase commences. However, in the KA23, the assistant PM introduced phase planning during re-planning sessions due to subcontractors reporting a lack of synchronization between plans. The updated master plan based on the phase plans proved to be more rational and realistic after re-planning sessions. The phase plans were an effective tool in coordinating the sequence of trades, and as a result, the team

used phase planning several times during the project. The team applied this level of planning particularly to plan areas with complex interfaces or short time allocations. The pace of production was adjusted accordingly, giving the subcontractors a shortened time frame per story once the deadline approached. The planned phases included the toilets, the sequence of the internal stories, and the basement cloakroom. Figure 8 shows an example of a phase plan used in the project.

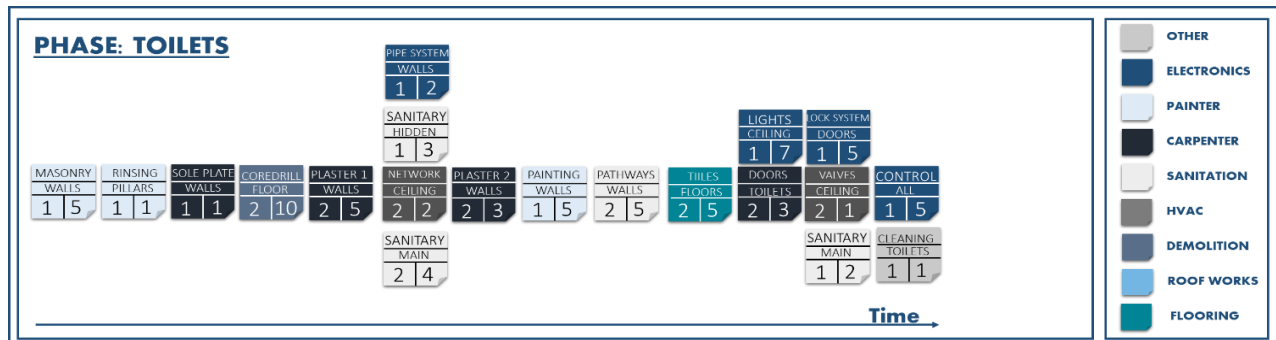


Figure 8. The KA23 Phase plan of the toilets

The Lean master plan. As in conventional planning, SELTOR created a legally binding MS Project master plan for the entire project, shown in Figure 9. The assistant PM used this plan to determine the project's milestones and facilitated pull planning sessions to plan backward. The project team collaboratively planned their activities on the visual planning board and discussed the dependencies between them. The subcontractor PMs and the foremen were present during the four-hour planning sessions, the PMs being the owners of the master plan. The project engineer digitized the master plan using Microsoft Excel and distributed it to the subcontractors for review before the next session.

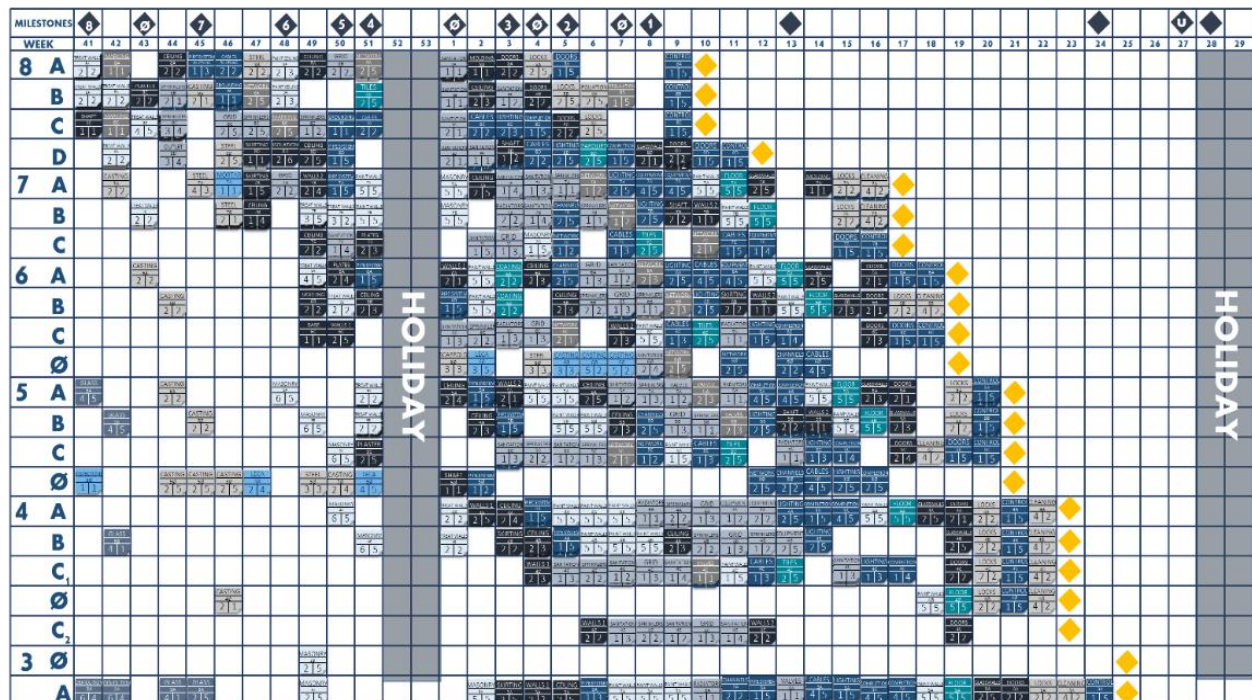


Figure 9. The KA23 Lean master plan from stories 8 to 4

The week plan. The week plan, shown in Figure 10, guides the daily workflow and is the most detailed level of planning. It includes main contractual activities, as well as activities not present on the master plan. The foremen added activities to the week plan for the week ahead during the Wednesday foremen meetings. The team collaboratively checked the plan four days per week during the daily plan checks. The yellow stickers indicate the RMCs identified during a plan check from week 48.

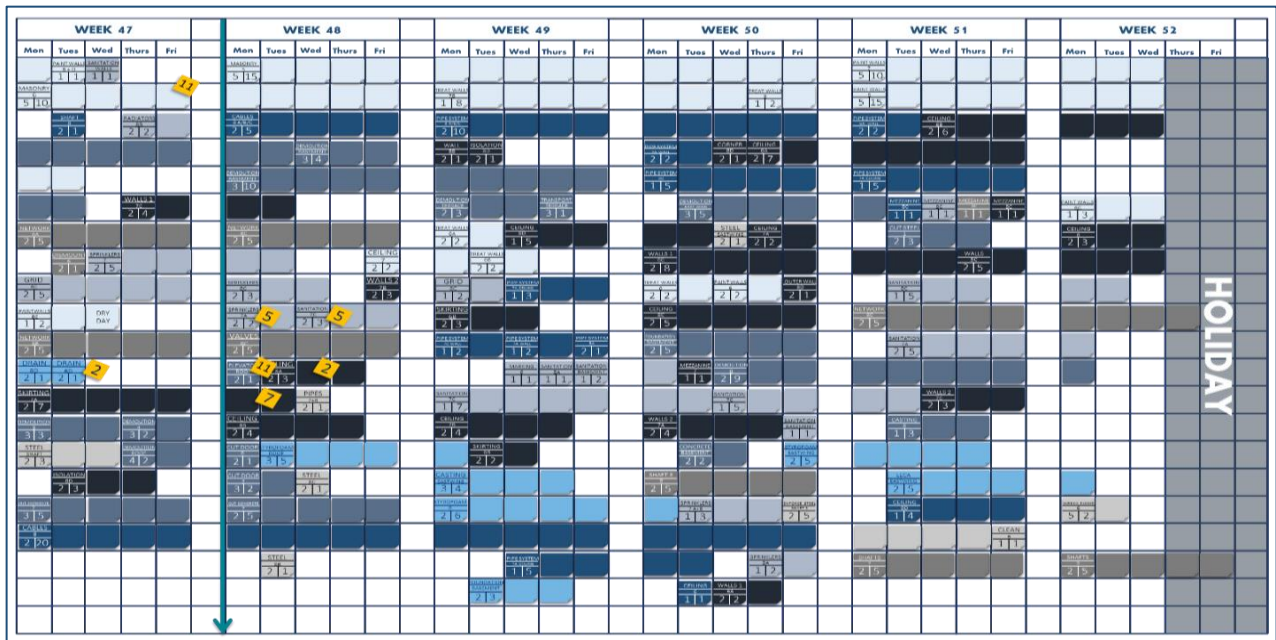


Figure 10. The KA23 Week plan from week 47 to 52

Continuous learning

KA23 applied continuous learning by providing weekly feedback on the planning accuracy. As opposed to the CPM and PERT, the LPS is reactive and assumes that task scheduling involves uncertainties and constraints. Allowing space for uncertainties makes the LPS suitable for construction projects, specifically renovation projects, such as KA23. The focus on plan realization decreases the propagation of variability to preceding tasks further down the stream. At KA23, the project engineer monitored the PPC and RMC overview and distributed the data to the team to show reoccurring trends. Figure 11 shows the PPC overview.

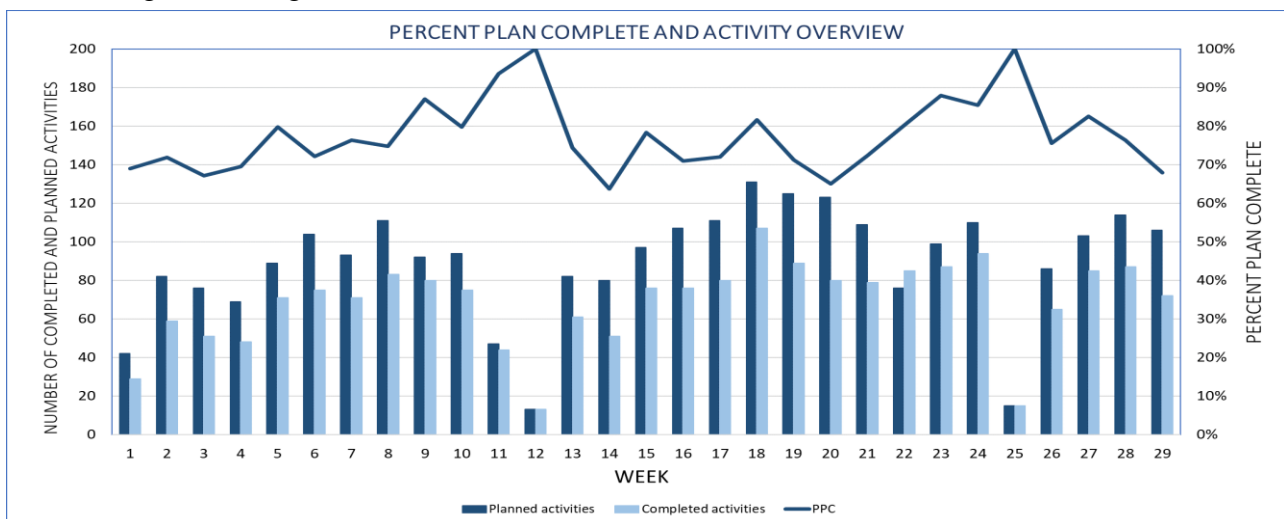


Figure 11. The PPC and number of activities on KA23 over 29 weeks

The aim was to have a PPC of around 80% so that the planning was accurate but not passive. The overall PPC on the project ranged from 64% to 100%, with an average of 77% over the 29 weeks tracked. Although a PPC of 100% would mean that the planning was passive, this occurred during holidays with minimal production, such as weeks 12 and 25. Decreases in the PPC have corresponding peaks in RMCs, such as in weeks 15, 20, and 29, indicating aggressive planning based on unrealized preconditions. These were periods with a high level of production and many planned activities. The first 12 weeks of using the LPS system show an overall increase in the PPC. However,

following the week 12 holiday, the PPC decreased and showed a lower trend than the preceding period. This may be related to an increase in the number of activities and subcontractors on site after week 12.

Limitations of the visual Lean planning at KA23

As the first project applying visual Lean planning at a full scale for SELTOR, KA23 was a learning experience and a valuable starting point to transfer knowledge within the organization. As when introducing any other new system, there are limitations to the planning methods applied at KA23. First of all, the KA23 contractor team was composed of several new employees with prior experience using visual Lean planning. Although the theory is the same, every contractor tailors the method to their needs. Thus, the team had diverging methods of applying Lean. Combined with the team not initially determining a unified method of managing the planning, there were situations of internal disagreement. In the context of implementing change in a culture that is reluctant to do so and generally skeptical of new methods, it is essential to agree on a unified approach.

LPS is a valuable tool during both the production phase and the design phase. There was an attempt to use Lean at the project's design phase by applying it to the engineering plan. However, the team experience with Lean at the time was inadequate to put it fully into practice. Therefore, visual Lean planning on KA23 focused solely on the production phase. The subcontractors frequently reported a lack of drawings, client decisions, engineering decisions, and clash detections as causes for delay. Thus, a visual Lean plan with engineering deliverables as milestones corresponding to the production plan would likely reduce the RMCs related to drawings and engineering by an estimated 60 percent. Another benefit of using visual Lean planning in both the engineering and design phases is that the plans are coherent and that H&S factors are well-planned from the beginning.

Even though the logistics of KA23 were complex, the team did not include H&S, logistics, and waste disposal activities in the planning process. The delivery system on the project proved to be problematic, as deliveries were often not complete or placed in the wrong zone. Further, the number of materials stored on-site indicated that some subcontractors were not following the JIT principle. Thus, enforcing the principles of the project and integrating the logistics system with the planning system are measures the management team should have taken. Introducing such measures could help to reduce the number of RMCs related to logistics and lack of materials, collectively accounting for 10.4 percent of the overall reported RMCs.

Moreover, the plan hierarchy for KA23 differs from the LPS proposed by Ballard and Howell, 1994. Instead of starting with phase planning to determine a rational work sequence, the standard LPS practice, master planning was the first step due to a recommendation from the external Lean consultant. The master plan is a mandatory contractual document with the client. However, it is not a valuable guiding document for daily operation because it lacks detail and dynamics. The team introduced phase planning due to the necessity of re-planning, as the subcontractors reported inconsistencies between the master and week plans. The inconsistencies were a result of foremen neglecting master plan activities and inaccuracies in the PM's planning. During three re-planning sessions, the team iterated the visual Lean master plan from stories eight to four. However, the team did not complete planning all nine stories until 29 weeks after project commencement, which added activities to the subcontractor's schedules that they had not considered. The result was an additional workload for the contractors in a period with an already high production level.

Figure 12 shows the impact of dependencies between activities on KA23, with 39.1 percent of the RMCs identified as incomplete predecessor activities. Despite this, the week plan did not display dependencies between activities as it was not structured by stories, like the master plan. The physical space in the management room constrained the plan's scope, as the wall space was the limiting factor. Although this is beneficial for keeping the plan concise, it was challenging to obtain a complete overview, as post-its were layered. The subcontractors identified the lack of visualization of dependencies as a deficiency in the structure of the week plan.



Figure 12. Distribution of the 13 Reasons for Missed Commitment

A 15-minute plan check four days per week with roughly 14 participants for 29 weeks costs the project an estimated 200,000 NOK. However, conducting plan checks allows for better control over the progress, as the team gets an indication of the status of the work daily. The number of plan checks was reduced by 50 percent of the original number due to Covid-19 restrictions. As a result, the team determined that it was more challenging to keep track of changes and notice problems in the production early. Although some contractors chose not to conduct daily plan checks, it was an essential element of the KA23 that enabled the SELTOR team to detect problems early.

Creating a culture of prevention rather than post-incident mending is favorable to all parties. Not only is this beneficial to identify and reduce health and safety risks, but it is an ideology that is generally useful in planning. Not using a look-ahead plan on KA23 resulted in the lack of a soundness check, identified by the team as one of the main limitations of the KA23 planning method. Implementing a soundness control would result in fewer RMCs, as activities would not progress to the next planning level until all preconditions were complete. Assuming that 40 percent of the RMCs could have been prevented by checking their preconditions and that each RMC requires an average of four hours of handling time, the team could have saved 1100 hours on the project. Provided a weekly time investment of one hour in foremen meetings to conduct a soundness check and an average hourly rate of 500 NOK per employee, the payoff of conducting a soundness check is 350,000 NOK. Thus, the payoff outweighs the investment. Simply eliminating the RMCs related to insufficient planning would save the project 140,000 NOK and 280 hours, given that each incident requires on average four hours of handling time. Additionally, once the culture has shifted, prevention occurs autonomously. Insufficient planning is the third most reoccurring RMC. Thus, a soundness check would enable more communication about activities before carrying them out.

SELTOR introduced RMC and PPC monitoring to the KA23 team a few weeks into the project but did not sufficiently explain its rationale. Not communicating the value of the metrics resulted in some subcontractors initially objecting to tracking the metrics in fear of sanctions for poor performance. Further, after identifying and communicating the RMCs to the KA23 team, SELTOR took no action to eliminate them directly. The absence of a process to manage the RMCs dramatically diminishes the potential for continuous improvement.

The KA23 client could have been more involved in the visual Lean planning process, particularly in the engineering and design phase. Lack of client decisions and engineering delays is one of the most common obstructions to progress in construction projects. At KA23, lack of client and engineering decisions was the sixth most frequent RMC, representing eight percent. Inviting the client to progress

meetings and planning sessions would reduce the processing time of engineering decisions and make the client aware of the impact of late decisions on the progress. A challenge is that including the client could inhibit the meeting participants from disclosing information on the actual status of work. Nonetheless, the visual Lean plans could have been shared with the client as they make excellent communication tools to share the project's status.

Lessons Learned

The research indicates that particular elements of the visual Lean planning method are essential for maximizing its potential. First of all, buildings are produced to order and have a unique set of requirements, stakeholders, and team composition. Therefore, Lean in construction differs from that in production in that it is not a standardized approach. Thus, it is imperative to tailor the method to the contractor and project's needs. The goal is to pull value from the customer and manage the workflow to improve the cohesion between planning and production. Improved project delivery results in an increased number of projects meeting their time and financial requirements.

Based on the KA23 and the experiences of the interviewed contractors, using an internal resource as a transient consultant is an effective method of facilitating the introduction of visual Lean planning tools to projects. As experienced in KA23, the external consultant had a very theoretical approach that overlooked the actual needs of the visual Lean planning system in practice. Therefore, communicating the rationale behind the use of Lean methods is a key success factor. Both the contractors interviewed and the KA23 team highlighted onboarding sessions as a vital first step in introducing Lean to the project team.

Further, integrating the design plan and the production plan through a visual planning system creates a coherent plan hierarchy that allows the team to manage project synergies. Additionally, using the look-ahead plan to ensure tasks are made ready for the next level of planning is essential for connecting the master plan to the week plan. The contractors in the industry deem the soundness check one of the most critical tools in the LPS, enabling early detection of problems and creating a culture of prevention. Additionally, phase plans at an early phase are beneficial in planning the interfaces and hand-off between disciplines.

To effectively communicate the location and dependency of activities, a well-structured plan is essential, not only for the Master plan but also for the other planning levels. This involves structuring by zones, showing dependencies, and using a streamlined post-it template. Most contractors allow project teams to choose whether to use a physical or digital post-it plan. A combination of collaborative physical post-it planning sessions and digital tools that reduce the need for manual administrative work is deemed optimal by most contractors. Additionally, BIMs are essential for clash detection to reduce rework and general communication tools in the visual Lean planning process.

Barriers and opportunities for change

All three contractors expressed that it is challenging to change the culture in construction. Tauriainen et al., 2016, deemed it challenging to implement new methods in the construction industry because projects involve many different companies. These companies have individual motivations, which may result in opportunistic behavior. Although new methods are slowly starting to permeate the industry, a cultural shift is necessary to reach smaller companies representing a large proportion of the Norwegian construction industry. Besides language barriers, cultural norms influence the way subcontractors respond to incentives. Subcontractors in the construction industry are used to financial sanctions and transferring responsibilities to other parties. Thus, a cultural shift in the industry is necessary for subcontractors to embrace the collaborative approach of visual Lean planning tools fully. One way to foster cooperation is to incentivize companies to collaborate and resolve problems through bonus arrangements or specific rewards that benefit the workers on site.

With the influx of Technology 4.0 in the construction industry, new possibilities are emerging. New technologies make it possible to visualize the construction site, the planning boards, and meeting rooms without being present physically. As emphasized by the pandemic, the construction industry is vulnerable to external forces due to low overall innovation and reluctance to change. However, adapting methods that enable operation remotely would make it easier for the industry to adapt to disruptions, like a pandemic. Further, integrating several project management tools with the plans, such as risk matrices, financial tools, and drawings would further increase the value of the plan, not just as a scheduling tool but as a comprehensive document to guide the project.

Conclusion

Visual Lean planning increases the cohesion between planning and production. The LPS is tailored to construction and improves accuracy in planning through increased collaboration, communication, and team involvement. The LPS is composed of dynamic operative plans that guide the daily work and reflect the conditions on-site for a practical planning and monitoring tool. As opposed to push planning, pull planning enables the team to determine the best method for reaching milestones, making them accountable to their promises.

The KA23 proved that the LPS system requires more active participation and management than traditional scheduling, but in return, it provides a system that detects delays before they occur. One of the primary deficiencies of KA23 was the lack of a soundness check by including a look-ahead planning level. Isolating and removing reasons for delays before they occur can save the industry millions in penalties and improve productivity. Additionally, KA23 did not actively use the plan to manage risks and logistics. Integrating H&S and logistics as part of the planning enables project teams to identify and mitigate risks before they occur. The most significant obstruction to progress on KA23 was disciplines causing delays for each other through dependent activities. Additionally, shortage of workforce, aggravated by the Covid-19 pandemic, shortage of materials due to an ineffective logistics system and not following JIT, and insufficient planning represent other reoccurring problems on the project.

The contractors with established methodologies have determined some essential elements of visual Lean planning through many years of experience. Their experience shows that implementing Lean in construction requires a management team that recognizes the value of Lean and can communicate this to the contractors in a unified manner. The contractors have also recognized the importance of including the client in the process. Most established contractors use a mixture of digital and physical post-it planning boards. As both methods have their benefits and drawbacks, the contractors deemed a combination the optimal method. The research indicates that introducing phase planning and well-structured plans that visualize dependencies are other vital elements of the LPS. Finally, the construction industry overlooks the importance of transferring knowledge, resulting in lost potential innovation progress and value creation. Through continuous learning and improvement, both the contractors and the project teams can overcome the increasingly complex context in which they operate.

Limitations of the research

The research methods provide a holistic analysis of visual Lean planning in practice by triangulation of data. However, there are several limitations to the study. Firstly, the research only reflects a portion of the project, as the construction project outlasted the research study by months. Another significant limitation is evaluating solely one Lean planning project. A comparative study between a conventional project and a Lean project would indicate the effects of introducing visual Lean planning methods. Expanding the study to include a broader spectrum of projects that differ in size, contractual form, and type would have created a versatile study of visual Lean planning tools. Further, the three contractors in the study are all large companies representing only one industry demographic and geographic location.

References

- Ballard, H.G., 1993, '*Lean Construction and EPC Performance Improvement*, ' 1st Annual Meeting of the International Group for Lean Construction, Espoo, Finland
- Ballard, H.G, Howell, G.A, 1994, '*Implementing lean construction: stabilizing workflow*, ' Catolica Universidad de Chile, Santiago, Chile
- Futurebuilt, 2020, '*Kristian Augusts gate 23*' Available at: <https://www.futurebuilt.no/Forbildeprosjekter#!/Forbildeprosjekter/Kristian-Augusts-gate-232> (Accessed 20.11.20)
- Jones, C, Medlen, N, Merlo, C, Robertson, M & Shepherdson, J, 1999 '*The lean enterprise*, ' BT Technology Journal, 17(4), 15-22
- Jurado, M.C, 2012, '*Visual Planning in Lean Product Development*', Available at: <https://www.diva-portal.org/smash/get/diva2:600974/FULLTEXT01.pdf> (Accessed on 10.01.21)
- Kelley, J.E., Walker, M.R., 1959, '*Critical-Path Planning and Scheduling*', Eastern Joint IRE-AIEE-ACM Computer Conference, pg. 160–173, Association for Computing Machinery, New York, USA
- KPMG, 2015, '*Climbing the curve*', Global construction survey 2015, Available at: <https://assets.kpmg/content/dam/kpmg/pdf/2015/04/global-construction-survey-2015.pdf> (Accessed on 01.01.21)
- Lean Construction Institute, 2017, '*LCI Lean Project Delivery Glossary*', Available at: [LCI_Glossary.pdf \(leanconstruction.org\)](https://www.leanconstruction.org/LCI_Glossary.pdf) (Accessed on 02.03.21)
- Parkin, P., 2009, '*Managing Change in Healthcare: Using Action Research*', SAGE Publications
- SINTEF, 2020, '*Framsikt 2050: Hvordan ser framtidens bygg- og anleggsnæring ut?*', SINTEF Community, Oslo, Norway
- Standard Norge, 2011, '*NS 8407:2011 Alminnelige kontraktsbestemmelser for totalentrepriser*' Available at: <https://www.standard.no/no/nyheter/nyhetsarkiv/bygg-anlegg-og-eiendom/>
- Statistisk Sentral Byrå (SSB), 2021, '*Landbakgrunn for innvandrere og norskfødte med innvandrerforeldre i Norge*', 2021, Available at: <https://www.ssb.no/innvandring-og-innvandrere/faktaside/innvandring> (Accessed on 27.03.21)
- Tauriainen, M., Marttinen P., Bhargav, D., Koskela, L. 2016, '*The effects of BIM and lean construction on design management practices*. ' Creative Construction Conference, Elsevier
- Womack, J.P, Jones, D.T, 1996, '*Lean Thinking – Banish Waste and Create Wealth in your Corporation*, ' Simon and Schuster, London, UK

Biography



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