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The Last Planner System®: State of the Art

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Abstract
Lean construction is an evolving philosophy introduced in the construction industry with the aim of delivering the project with maximum value, continuous flow, and improved reliability. Last Planner System® (LPS) is an important key lean technique, which increases the reliability of planning and reduces the variation at the construction site. LPS is an example of a production planning and control system that has been successfully implemented and applied to complex construction projects to improve workflow reliability, production performance and to promote production control by engaging all members of the project team. An extensive literature review was carried out to understand the origin, principles, planning stages, effectiveness, benefits, and barriers in implementing the Last Planner System in the construction industry. Finally, the areas that need further research are highlighted and the need for incorporating LPS is emphasized.

Keywords
Construction Planning, Lean Construction, Last Planner System®, Productivity, Look Ahead Schedule, Barriers, Benefits

1. INTRODUCTION
Poor project management is one of the main reasons for the delay in construction projects (Alsehaimi and Koskela, 2008). Planning and reducing delays are the most efficient ways to increase the productivity of any project. Lean Production was developed by the Toyota production system in the 1950s led by Engineer Ohno who was committed to eliminating waste (Dakhli et Lafhaj, 2018). The core concept behind Lean Production is to enable the flow of value by creating work steps while eliminating non-value steps. Lean production ideas were first formulated through the TFV (Transformation-Flow-Value) theory of production (Abdelhamid et Salem, 2005, Dakhli and Lafhaj, 2018). In Lean, planning and control are considered to be complementary and dynamic processes throughout the entire project (Alsehaimi et al. 2009). Lean-based tools have emerged and have been successfully implemented in construction projects with the focus on increasing value for customers and making profits (Salem et al. 2005). Poor performance in the construction industry is mainly because of uncertainty and variability in the workflow (Aziz R and Hafez, 2013). LPS is an important key lean technique that increases the reliability of planning and reduces the variation at the construction site (Ballard and Howell, 2003, Bertelsen, 2004). According to the Lean Construction Institute, the companies using the LPS have been able to deliver the project on time and at budget under stress-free production planning and control processes (Abdelhamid and Salem, 2005). This literature review aims to provide a synthesis of the origin, principles, benefits, and barriers in implementing LPS. An extensive literature review of studies published from 1992 to 2022 was done to identify the existing benefits and barriers which can be used by future researchers to propose potential solutions. This paper is organized into 4 sections. Section 2 deals with the Methodology; Section 3 describes the origin of the Last Planner System, Principles, Planning stages, Applications of the Last Planner System, Benefits and Barriers in implementing LPS; Section 4 presents the conclusion and future research direction.

2. METHODOLOGY
A critical and comprehensive analysis of the current knowledge on the Last Planner System is provided in this narrative literature review. The literature review analysis is very important to cover the state-of-the-art progress about the studied topic and cover its different aspects. During the conduction of this study, the authors found six previous articles that were conducted to review the related literature about LPS (Desarrollo, 2019; Kortenko et al., 2019; Babalola et al, 2020; Yu et al, 2020; Schimanski, 2020; Sbiti et al, 2021). Even though all of these works were very

important, none of these articles covered the same objectives this study does. In addition, most of the previous work aimed to link LPS with other topics such as Building Information Modeling (BIM), design management, and other lean tools.

To achieve the objectives of the study, the study used a search in the title of the articles published on Google Scholar between the years 1992 and 2022. The selection of the year 1992 was because it was the year that witnessed the first work that aimed to present the concepts of lean to the construction industry by Koskela (1992). The search included: ((last planner) AND (origins OR benefits OR barriers OR principles OR applications OR levels)). The inclusion was for the articles that were written only in English. The total number of selected articles was 50.

3. RESULTS

3.1 ORIGIN OF THE LAST PLANNER SYSTEM

Construction projects require planning and control throughout the life of a project. Glenn Ballard and Greg Howell have been involved in the process of developing LPS since 1992 (Kalsaas et al. 2009; Ballard and Tommelein, 2012; Daniel et al. 2015, Dakhli and Lafhaj, 2022). LPS is a system for production planning and control method adapted from the manufacturing industry to improve the predictability and reliability of the production process (Mossman 2012; Mejia et al. 2016). The Last Planner is a holistic approach which means that every part of it is necessary for lean project planning and execution. Last Planner breaks down larger tasks into specific work assignments, which arethen assigned to individual teams to be completed in the specified time frame (Santos and Tokede, 2016). Initially, LPS was developed to increase the quality of assignments in the Weekly Work Plan (WWP) and then extended to design from construction. During the process of development, the focus was shifted from increasing productivity to improving the reliability of workflow (Ballard, 2000). Over the years, LPS has been implemented in many countries demonstrating its effectiveness in different work cultures (Alarcon et al, 2005; Viana et al. 2010; Daniel et al. 2015). According to the website of Lean Construction Institute, the Last Planner System is defined as: "*The collaborative planning system which integrates should, can, will, and did planning and perform constraint analysis, and weekly plans based on commitments and reliable promises and learning from measuring Plan Percent Complete and analyzing variance*".

LPS is a planning and control technique, which increases the productivity of the project by applying these three principles: (1) By coordinating the last planners through regular meetings, (2) Through commitment and responsibility of these last planners (Hamzeh et al, 2009 and Seppanen, 2010) and (3) By the representation of the obtained results using Percent Plan Complete (PPC). The primary goal of LPS is to improve the workflow by eliminating waste and to complete the work as and when promised. It replaces unrealistic planning with collaborative planning by evaluating the worker's performance and potential in completing the assigned work in planned time. Production unit control and workflow control are the two important components of the system. At the production level, the key performance dimension of the planning system is the output quality, that is the quality of plans made bythe last planner system. Production processes can be grouped into three different categories: 1) Conversion of inputs to outputs, 2) Flow of materials and information through time and 3) Value generation for customers. (Ballard, 2000). According to Koskela (1992), the following are the principles for a production control system that also holds good for the Last Planner System: The work can be started only when all the resources required for the completion of the work are available. This principle is also called Complete Kit by Ronen. a) Assignments should be monitored and measured using PPC, which is the percentage of several completed planned activities divided by the total number of planned activities. b) Identification and removal of causes for non-realization which helps in continuous improvement. c) A buffer of tasks has to be maintained so that if the assigned tasks become impossible to execute, then the workers can shift to another task. d) It also helps to avoid production loss and decrease productivity. e) Look ahead Planning is suggested so that the prerequisites of the forthcoming assignments can be made ready in advance.

In general, push and pull are the two ways by which workflow can be regulated in production control. Traditionally construction schedule follows a push system. In the push system, the materials and information are released according to the preassigned due dates or target completion dates whereas in the pull system the materials and information are released according to the work progress. Resources are released into the production process only if the process can do that work (Ballard, 2000). In the Look Ahead process, assignments are made ready using pull techniques. Therefore, LPS is a type of pull system. Reliability greater than the supplier lead time is required for the pull system to be effective. The Last Planner System pulls activities by reverse phase scheduling through resource optimization and proper team planning. This tool is similar to the Kanban system and production leveling tools in Lean manufacturing (Salem et al. 2005).

3.2 PRINCIPLES OF THE LAST PLANNER SYSTEM

The five important principles of the Last Planner System are 1) Detailed planning of the work as the start date of the work approaches; 2) Collaborative planning with those members who will execute the work; 3) Identification and removal of constraints of the planned work; 4) Make a reliable plan and promises and learn from variance; 5) Elimination of waste and continuous improvement based on previous learnings to avoid reoccurrence of failure (Daniel et al, 2015). The last Planner System helps to maintain a reliable workflow. In weekly meetings of push planning the work that SHOULD be done is planned; whereas, in pull planning, the work that CAN and WILL be done is planned and considered (Dakhli and Lafhaj, 2018). Last Planner transforms what SHOULD be done into what CAN be done (Stratton et al, 2010). LPS consists of five levels of planning processes: Master planning, Phase planning, lookahead planning, Weekly work planning, and learning (Ballard 2000; Ballard and Howell 2003; Daniel et al. 2019; Mossman 2012).

Master Scheduling: It is the general long-term plan which is driven by the project objective and design criteria. Aligning the team and the key milestones are set within the master schedule. It also identifies the time required for the completion of each activity. The Work Breakdown Structure of the project is recognized in this phase. It defines some top-level tasks of work breakdown structure based on initial scope, time, and budget. During this phase, execution strategies are developed and the feasibility of completing the work within the given time is analyzed and demonstrated. It forms the basis of Phase planning (Daniel et al, 2015).

Phase Scheduling / Collaborative planning / Reverse phase scheduling: This phase provides a more reliable and detailed work plan and objectives that could be deliberated as targets. This phase includes strategic planning of work segments which involves pulling the schedule backward to avoid mistakes later. It also helps in providing a detailed weekly work plan (Seppanen et al, 2010).

Look Ahead Planning / Make work ready planning: Look Ahead a Schedule is a tool for workflow control. It is in the mid-level of the planning hierarchy, in between front-end planning and detailed planning. It involves mapping the resources with workflow and making the task ready so that they can be completed at the right time and also ensures production proceeds at the optimum level (Ballard, 2000). The objectives of the look-ahead schedule include identifying and eliminating the constraints and also reducing uncertainty (Daniel E, 2017). Look Ahead Plan helps to start the activities on time and allows only the activities with available prerequisites to be started (Ballard, 2000). Look Ahead acts as a forecast of activities to be performed in the next 3 to 12 weeks and makes the schedule of the assignment for the following weeks (Santos and Tokede, 2016).

Weekly work planning / Commitment planning: In this phase, specific resource planning and assignment has to be made for the successful completion of the work. It is carried out every seven days in the presence of the last planners. It includes planning each day's work and sequencing next week's work to create a reliable workflow plan. The tasks planned during the previous week are reviewed to create a plan for the week ahead. Only the tasks which meet the four production criteria are allowed into the Weekly Work Plan. The production criteria are 1) well defined and detailed task breakdown 2) the task that can be done 3) the tasks that are sequenced 4) properly sized task. The tasks which do not meet these criteria are called workable backlogs. They are retained and not allowed into the WWP. (Daniel et al. 2015).

The key metrics used in LPS implementation are Percentage Plan Complete (PPC), Reasons for Non-Completion (RNC), Task Made Ready (TMR), and Task Anticipated (TA). Root causes of variance are analyzed and continuous improvement is made in this phase which contributes to the minimization of the problem in long term. Last Planner System uses lean construction techniques such as Just in Time delivery, Value Stream Mapping, Pull planning, etc. The general implemented components of LPS include Weekly Work Plan (WWP), Percentage Plan Completed (PPC) (Daniel et al. 2015; Hamzeh et al. 2015), Reasons for Non-Completion (RNC), Look ahead and Daily Huddle meeting. Extensive quantitative research has been done by Daniel et al (2015) on LPS implementation based on 57 IGLC reports from 16 countries. According to the research, PPC, WWP, RNC and Look ahead are the most commonly used components (Daniel et al, 2015, Hua and Schwartz, 2021).

One way of developing the involvement and communication among laborers is through visualizing the required information at the workplace. Increased visualization is an effective way of communicating the key information related to safety, schedule, and quality to the workers. Workers can be certain of elements such as workflow, performance targets, and specific required actions. Setting up instructions for material and equipment storage, reduces waste, such as the time for searching and transportation. These plans can then be displayed which is a form of visual management and referred to convey the performance standard (Mastroianni, 2003,).

3.3 APPLICATIONS OF THE LAST PLANNER SYSTEM

Planning is a key element for successful production generating high profit (Friblick 2009). Applying LPS in the design stage helped in identifying the conditions of satisfaction of the customers at an early stage. It gave a clear picture to

the design team, of where to focus on the design. The inputs from the construction team to the design team helped in eliminating inefficient design which would have led to rework in the future. (Miles 1998). Still, there are some questions regarding the implementation and effect of LPS in the design stage. Hamzeh et al.2009 researched the application of LPS in the design stage during the construction of Cathedral Hill Hospital, California. Few adjustments and modifications have been made to introduce LPS in the design stage. Ballard emphasized the three factors which differentiate production control during design, 1. Increased uncertainty decreases the ability to foresee the tasks in the future 2. Effect of increased speed of execution and constraint removal to make tasks ready for execution 3. Interdependencies between tasks in design accelerate the complexity of work (Hamzeh et al 2009). The applications of LPS in various projects are tabulated below in Table 1.

Table 1: Applications of the Last Planner System

Project	Outcome after implementing the LPS	Methodology	Reference
Small high-tech project	Increase in PPC to 75%, the design was completed one week earlier than expected and design costs were reduced by 7%	Implementation of LPS in design and construction stage	Miles 1998
Construction of library in Campinas, Brazil	Completion of project on time, decrease in cost by 42%.	Weekly preparation of medium-term schedule, Detailed weekly work plan (daily plan).	Conte 1998
CCSR Project – Laboratory building for Stanford University	Active involvement of team members	Implementation of LPS, constraint analysis, identifying the readiness of assignments and taking actions to make them ready, and measuring PPC	Ballard 2000
Next stage (Amphitheatres in US cities)	LPS was 44% more effective than a traditional management practice	Implementation of LPS in the Design and construction stage	
Pacific Contracting	Achieved average PPC level of 76%	Implementation of LPS by specialty contractor, First Run Studies	
Old Chemistry Building Renovation, Linbeck Construction	Achieved PPC level of 85%	Implementation of LPS	
Zeneca, Barnes Construction	Achieved PPC near 100%	Implementation of LPS, constraint analysis and make ready	
77 construction projects in Chile	Increase in PPC from 63% to 71% in 3 years.	The first group involved a basic level of implementation with importance on WWP and an informal Look Ahead Plan. In the second group, emphasis was given to formal look ahead planning, workable backlog, and learning.	Alarcon et al. 2005
Construction projects in Sweden	Decrease in time spent on working with non-value-added activities. Labor efficiency increased up to 8.7%	Implementation of Last Planner System	Friblick 2009

Cathedral Hill Hospital, California	Increased communication among designers and team members and owners had an important role in LPS implementation	Implementation of LPS in the design process	Hamzeh et al. 2009
Two Construction projects in Saudi Arabia	Increase in PPC from 69% in the first week to 86% in last week in the first project and 56% to 82% in the second project.	Implemented in four phases. PPC measures and reasons for non-completion were analyzed.	Alsehaimi et al. 2009
Seven construction projects in Mexico	Gives a better understanding of program control, coordination of team members, Better visualization, and clear vision	Training and Implementation of LPS, analysis of critical points, and effective measures to improve implementation	Cerveró-Romero et al. 2013
Construction of 1534 apartments in Fortaleza, Brazil	PPC level of 70% to 80% was achieved	Training and Implementation of LPS and Visual management for one year	Barbosa G et al. 2013
Construction site in South Western China	Challenges in implementing LPS are the exclusion of foremen in the planning process, lack of updates on planned information, and lack of involvement and cooperation among stakeholders	Implementation of LPS of production control, identify constraints, and measure PPC	Huang H 2015

3.4 BENEFITS OF IMPLEMENTING THE LAST PLANNER SYSTEM

The benefits of the LPS across several countries around the world can be realized from the outcomes of the projects where it has been implemented (Ballard and Howell, 2003). Successful implementation of the LPS can result in smooth workflow, reliable work plan, increase in productivity, improved communication, cost minimization, reduced delivery time, and better participation among team members and subcontractors (Ballard 2000; Fiallo and Revelo, 2002; Koskenvesa and Koskela, 2005; Kim and Yang, 2005; Fernandez-Solis et al. 2012, Albalkhy and Sweis, 2019). Proper implementation of the LPS can also improve safety in the construction site. Based on the literature review, the various benefits of implementing LPS are listed in Table 2 (Ballard 2000; Formoso and Moura 2009; Hamzeh 2011and Fernandez-Solis et al. 2012).

Table 2: Benefits of the LPS implementation

Benefits	Fernandez-Solis et al (2012)	Viana et al (2010)	Alarcon et al (2002)	Fiallo et al (2002)	Mejia Plata et al (2016)	Johansen et al (2003)
Increased reliability in planning	✓	✓				✓
Improvement in project delivery	✓	✓	✓	✓	✓	✓
Better Team communication	✓	✓				
Expanding knowledge and learning among team members	✓	✓	✓			
Improvement in supply chain integration	✓		✓			
Better construction management practices	✓	✓				
Increase in quality of work	✓					

3.5 BARRIERS IN IMPLEMENTING THE LAST PLANNER SYSTEM

According to Leong and Tilley (2008), not identifying the factors that influence the successful implementation of the LPS may lead to the inability of the organization to understand the efforts which should be improved, where these efforts should be focused, or what effort is required to attain the better results. Studies have reported that organizational resistance followed by a negative attitude towards the new system (Albalkhy et al, 2021), lack of management support and the lack of exposure to the benefits and need to adopt the LPS, and difficulties in understanding its concepts to be

significant barriers to the successful implementation of LPS (Daniel E I 2017; Ryan et al. 2019). Other factors include the use of incompatible procurement strategies and focus on cost (Conte 1998; Johansen and Porter, 2003), less integration of the supply chain and subcontractors (Ayalew et al, 2016), culture, and structural problems within the organization (Johansen and Porter 2003). Based on the literature review, the various barriers to the implementation of the LPS are shown in Table 3.

Table 3: Barriers in implementing the LPS

Barriers	Fernandez-Solis et al 2012	Viana et al .2010	Alarcon et al 2002	Koskenve-sa and Koskela 2005	Mejia Plata et al 2016	Ballard 2000	Alsehai-mi et al 2009	Garza and Leong 2000
Organisational resistance to change	✓	✓	✓	✓	✓		✓	✓
Lack of experience and training	✓	✓	✓		✓	✓		
Lack of time to implement		✓	✓					
Late or partial LPS implementation	✓		✓	✓			✓	
Lack of support from stakeholders	✓				✓	✓		✓
Misinterpretation of PPC indicator	✓		✓					✓
Poor use of information obtained from LPS implementation	✓	✓				✓		
Lack of leadership and commitment from management to implement LPS	✓		✓	✓		✓	✓	✓
Lack of collaboration among team members	✓							
Lack of understanding of LPS among human capital						✓		
Lengthy procedure to get approval from top management and client							✓	
Contract issues						✓		✓

4. CONCLUSION

Implementing lean and LPS in construction projects significantly improves the efficiency and productivity of the construction industry. Introducing LPS in the construction industry has several benefits such as increased process transparency, reduced project variability, and balance flow improvement. LPS is a dynamic process that has constantly evolved over the last 25 years. At present, research and studies have been conducted to integrate LPS with other systems such as BIM, Location-Based Management System, Takt Planning, etc. (Daniel et al, 2015). To bring out the developmental change in the field of construction, acceptance of lean tools and LPS is mandatory. In this paper, the evolution of LPS and the impact of adopting LPS in the construction industry are explained. The barriers in implementing LPS have been discussed and the need for implementing LPS in the construction industry has been emphasized. An efficient look ahead planning and constraint removal before and during execution can have a great impact on reliability measured by PPC and the entire project duration (Hamzeh et al, 2016). By implementing LPS, construction companies can have a better understanding of waste that is generated which can lead to improved efficiency in construction activities.

4.1 CONTRIBUTION OF THE STUDY AND FUTURE DIRECTIONS

The current study aims to contribute to the existing efforts made to disseminate the practices and culture of lean in the construction industry by providing a summary of the origin, principles, application, benefits, and barriers of lean construction in general and LPS in particular. This summary is useful for researchers and academics to present new directions for future research. It also serves as a reference for practitioners who are aiming at improving the levels of lean adoption in their projects.

Future research can be conducted on construction organizations that have implemented the LPS concept by observing their practices on-site and by developing the adaptations to be made in LPS. A qualitative research approach is suggested to investigate the nature of the significant barriers identified and to propose strategies for overcoming barriers to implement the LPS. This paper also proposes that practitioners focus on the interaction between LPS and BIM for further research

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