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FRAMEWORK FOR USING LPS IN DESIGN ON IPD PROJECTS

Negar Mansouri Asl[1], Nazanin Najafizadeh[2] , Mahboobeh Fakhrzarei[3], Ahmed Hammad[4], and Farook Hamzeh[5]

ABSTRACT

Design in nature is an iterative and interdependent process. Previous research shows that in some projects, 50% of this process contains waste. The Last Planner System (LPS) proved its efficiency in planning and controlling the execution phase. However, due to the nature of the design process, implementing LPS at this stage contains many constraints. Results show that the Integrated Project Delivery (IPD) and LPS together can significantly improve design workflow, still some issues remain that do not let the IPD project achieve the full potential of LPS in managing a design process. In this research the main constraints are studied and divided into five categories. Recently, many researchers studied the benefits of implementing LPS and how to optimize this method, especially in the execution phase, but there is no integrated framework that contains the available tools and techniques for overcoming constraints in using LPS at the design process. This study indicates that multiple strategies need to be adopted for increasing the applicability of LPS at the design process of a construction project. This paper proposes an integrated framework for addressing design constraints and optimizing the applicability of LPS in the design process on IPD projects.

KEYWORDS

Last Planner System, Integrated Project Delivery, design process, workflow, lean design

INTRODUCTION

In construction, design processes are dynamic and complex (Khalife et al., 2018). Hamzeh et al. (2009) stated that because of the high uncertainty in design tasks, this process is not easily predictable. Some sources of uncertainties include task duration, task sequence, task scope, task prerequisites, and constraints. Also, the design process may be responsible for a considerable amount of waste: design error is one of the primary sources of waste in the construction industry (Breit et al., 2008; Ko & Chung 2014). Moreover, the design process comprises positive and negative iterations that can significantly affect the quality of the

[1] PhD candidate, Civil and Environmental Engineering Dept, University of Alberta, Edmonton, AB, Canada, nmansour@ualberta.ca, orcid.org/0000-0003-2402-4341

[2] MSc student, Civil and Environmental Engineering Dept, University of Alberta, Edmonton, AB, Canada, nnajafiz@ualberta.ca

[3] MSc student, Civil and Environmental Engineering Dept, University of Alberta, Edmonton, AB, Canada, fakhrzar@ualberta.ca

[4] Associate Professor, Civil and Environmental Engineering Dept, University of Alberta, Edmonton, AB, Canada, ahammad@ualberta.ca,

[5] Associate Professor, Civil and Environmental Engineering Dept, University of Alberta, Edmonton, AB, Canada, hamzeh@ualberta.ca, orcid.org/0000-0002-3986-9534

product. Negative iterations are hard to predict and eliminate during the planning process because this process contains complex tasks that have mutual interdependencies and need sharing of incomplete information (Hamzeh et al., 2009). All these uncertainties together increase the difficulty of planning and controlling the design process.

The Last Planner System (LPS) is a production management system for improving workflow reliability (Ballard & Howell, 1994). LPS is one of the lean construction techniques that has been used in the construction industry since 1990 (Perez & Ghosh, 2018). The LPS has been used successfully on construction projects to improve reliability of planning, production performance, and creating a predictable workflow (Hamzeh et al., 2009). However, previous studies reveal some difficulties and constraints associated with applying LPS (Alarcón et al., 2008; Perez & Ghosh, 2018), especially at the design stage, which contains noticeable iteration process and interaction between different parties (Hamzeh et al., 2009).

LPS has been more successfully applied in the execution compared to design due to inherent differences between the two phases. The main factors that differentiate the production control during design process are 1) predictability reduction of the future tasks' sequence because of higher uncertainty of ends and means, 2) inappropriate constraints removal as a result of increasing the speed of design tasks' execution, and 3) increasing work complexity and planning process due to design tasks' interdependencies (Ballard et al., 2009, Hamzeh et al., 2009).

The mentioned differences between the design and production phase increase the difficulties in implementing LPS in the design compared with the execution. Simonsen et al. (2019) analyzed a case study that implemented LPS at the execution phase, however LPS in this project failed at the design stage and project participants preferred to continue with the traditional planning and control systems. The researchers concluded that implementing LPS requires enthusiasm and commitment, which take time to build in an organization.

Aside from design constraints, shifting from traditional planning methods to LPS is challenging, because most construction companies tend to use approaches that they are already familiar with. LPS requires a high level of communication and collaboration, which can be facilitated through Integrated Project Delivery (IPD). In an IPD project, the whole team works as a single unit and shares responsibility in risk and reward. The IPD approach tries reducing later conflicts such as extended schedule and cost overrun by improving the collaboration (Gomez et al, 2018).

In this research, after reviewing the previous studies, the main design-related constraints that lead to reduced efficiency of using LPS are divided into 5 categories: 1) changing priority and design task sequence, 2) negative iteration, 3) lack of communication and lean culture, 4) lack of proper training, and 5) time pressure. Moreover, regardless of the number of studies on implementing LPS in the construction industry, not many studies try to develop an integrated framework that contains the available tools and techniques for improving the efficiency of LPS in design and overcoming the related constraints. The objective of this paper is to propose a framework which contains the available approaches to address the challenges that reduce the efficiency of LPS during the design phase of IPD projects.

METHODOLOGY

In this study design science research (DSR) is used to achieve the aforementioned objectives. DSR is a research strategy driven by field problems. This approach tries to provide information to be used in the design and implement actions, processes, or systems in practice to reach the desired goals. (Simon, H. A, 1996; Van et al, 2016)

Hevner (2007), briefly analyzed the DSR within three relative cycles of activities;

Relevance Cycle: a good DSR starts with recognizing and displaying problems and opportunities in a real environment. Relevance cycle provides the research requirements as inputs as well as criteria for evaluating the results. In this research, the problems recognized from the literature review were discussed with experts to assure that these are real problems.

Rigor Cycle: in DSR, a foundation for rigorous design science is formed from a vast knowledge base of scientific theories and engineering methods. The knowledge base contains the experiences and expertise for defining the state-of-the-art as well as the existing artifacts and processes in the application domain of the research. In this study, previous research, the author's observations, and experts' opinions have been used.

Design Cycle: this is the internal and core cycle of the DSR. This cycle iterates between forming an artifact, evaluating it, and receiving feedback to better refine the design. Here, a set of interviews have been conducted to receive feedback and refine the proposed framework.

The data sources used in this paper are literature reviews, interviews with experts and the author's experience of using LPS on IPD projects. This research was conducted through four major steps to achieve the goals: 1) Investigate the previous research in implementing LPS in design, especially in IPD projects. Analyze and categorize the main constraints, solutions, and recommendations. 2) develop an artifact to reduce the design constraints during LPS implementation. 3) Interview with the experts in this field to achieve more realistic information and feedback about the developed framework. 4) refine and improve the developed framework.

DESIGN CONSTRAINTS IN IMPLEMENTING LPS

1) CHANGING PRIORITY AND DESIGN TASK SEQUENCING

Master scheduling is the first step in implementing LPS and contains recognizing milestones of the projects, in which deliverables are mapped and identified in order to determine the completion date (Hamzeh et al., 2009). Successful implementation of the master scheduling step is necessary to prevent the possibility of milestones' priority changing. Increasing the priority changes leads to failure in phase and pull planning and consequently, causes workflow interruption.

Although changing milestones sequence can lead to losing value in phase planning, in some cases prevention is not feasible due to complexity of the project. Nevertheless, precisely identifying the milestones and their deliverables in the master schedule can significantly increase the efficiency of LPS at the design stage by reducing unnecessary changes.

Besides changing sequence of milestones, inappropriate design task sequencing can create waste in the process. Design tasks contain interdependencies between different engaged parties, which can lead to workflow interruption (Khalife et al., 2018).

2) NEGATIVE ITERATION

Iteration is an inseparable component of the design process and can be divided into two parts: negative (non-value-adding) iteration and positive (value-adding) iteration. For generating value in the design process, positive iteration is an essential factor (Ballard, 2000). A positive iteration can lead to improve the project value through an innovative idea.

However, a negative iteration causes waste in time, cost, and failure in participant's commitments.

Negative iteration can have different sources. One of the well-recognized causes is errors. When errors in design are discovered, then rework is mostly required (Lopez & Love, 2012). Informal surveys of design teams demonstrated that negative iteration dedicated 50% of design time to itself (Ballard, 2000). Erroneous actions are often identified as misinterpretations, miscalculations, and omissions (Lopez et al., 2010). Different reasons cause errors and many studies have been conducted in root cause analysis of error in the design process. For instance, Lopez et al. (2010) stated that human deficiency of cognitive ability to respond to cultural, social, and physical conditions can lead to inaccurate decisions and errors.

Notably, the other defect raised by wrong task sequencing, as mentioned in the previous subsection, is increasing the iterative loops and waste in the process.

3)LACK OF COMMUNICATION AND LEAN CULTURE

Right culture works as a foundation and builds up trust and efficient communication. Trust and communication have a two-way relationship. It is not possible to have clear and efficient communication without existing trust among participants and vice versa. Moreover, improving lean culture will reduce the resistance to change in an IPD project.

Lack of communication and solely design decision-making raises the project's complexity and increases the difficulties in managing the workflow (Ballard & Koskela, 1998; Khalife et al., 2018). On the other hand, improving communication results in higher clarification in case any conflicts occur. The integrated project delivery method can create a well-functioning collaboration among contributors through positive thoughts about each other (Falch et al., 2020).

4)LACK OF PROPER TRAINING

Despite the approved advantages of using LPS, many developing countries have not executed LPS in their projects (Hamzeh et al., 2016).

In an IPD case study, Hamzeh et al. (2009) mentioned the necessity of training. The transition team recognized the importance of providing general training in lean methods and particular training in LPS for the staff. Many failures in applying LPS have been reported in different research due to the lack of training. Dave et al., (2015) explored a construction project that failed to implement LPS, they only used weekly work planning in this project, and lack of training was reported as one of the main reasons for LPS failure.

5)TIME PRESSURE

Even though LPS improves the reliability of scheduling through pull planning, some findings report time pressure trigger LPS failure.

The Tonsberg project, a case study on a large hospital, is an example of failing LPS in design because of time pressure (Simonsen et al., 2019). In this project, intensive planning was running out in the design process, and the short time between the design deadlines and the start of the execution phase induced additional challenges to the design team, which caused frustration and led to discontinuing the LPS in the design phase. Moreover, time pressure is stated as the reason for holding the participant back from the implementation of new methods in projects (Aslam et al., 2020).

Through analyzing previous research, mapping design processes, and authors observation of using LPS in IPD projects, we found that the design constraints are interdependent. Figure

1 tries to show how these constraints are linked and impact each other. Therefore, leaving one unsolved will cause emerging the other constraints and interrupt the whole process. The number on the top left corner of each box show the constraints group that they belong to. The yellow color demonstrates that usually at this stage the teams are not aware of the importance of these constraints. The negative impact becomes more and more obvious when the color is changed to orange and red and when the color turns to red, a workflow is interrupted and everyone becomes aware of the problem.

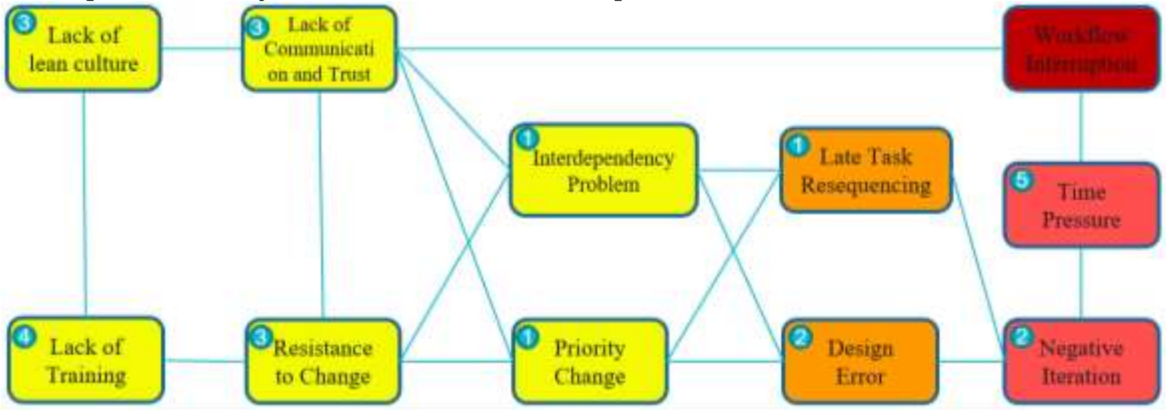

Figure 1: Design process constraints are interdependent.

RESULTS AND DISCUSSION

EXPERT INTERVIEWS

For assuring that the mentioned constraints are the reasons for making LPS challenging in the design stage of construction projects, a set of interviews with four experts in this field was conducted. The interviewees included four managers and all the participants have valuable experience in using LPS during different IPD projects. Participants answered questions related to each constraint's category. Also, from their answers, the magnitude of the negative impact of these constraints during the design process was analyzed.

Figure 2 depicts the negative impact of design constraints versus time for each constraint's categories based on average answers from the interviewees. The results from interviews show that the lack of communication and lean culture and lack of proper training have a significant impact during the whole design process.

Lack of communication shows its highest negative impact at the beginning of the process design. From the interviews, it is understood that mostly in the concept design stage, people try to show that they communicate well. However, when the process design starts, lack of proper communication and culture shows its negative effect when the design team needs to collaborate and decide together. Lack of proper training has a noticeable negative effect on the concept design, beginning and end of the process design. At the beginning of the project, enough training is required to build the right culture and to bring all the team members on the same page, and at the end of the process design due to overlapping the design and execution phase, training is required to improve the collaboration between different teams.

On the other hand, the highest negative impact of time pressure reveals at the beginning of process design. Negative iteration as well as changing priority and design task sequencing have a similar negative impact during the design process. They both have a low impact at first, and the further design goes, negative impact increases. It is mainly because of reducing the flexibility of changing the schedule and design close to the end of process design.

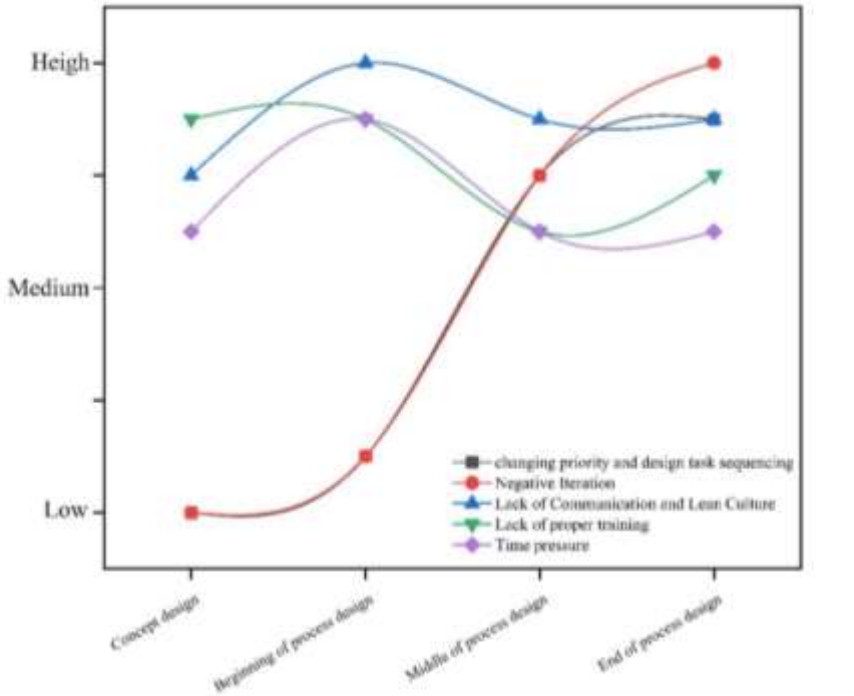

Figure 2: Negative impact of design constraints versus time.

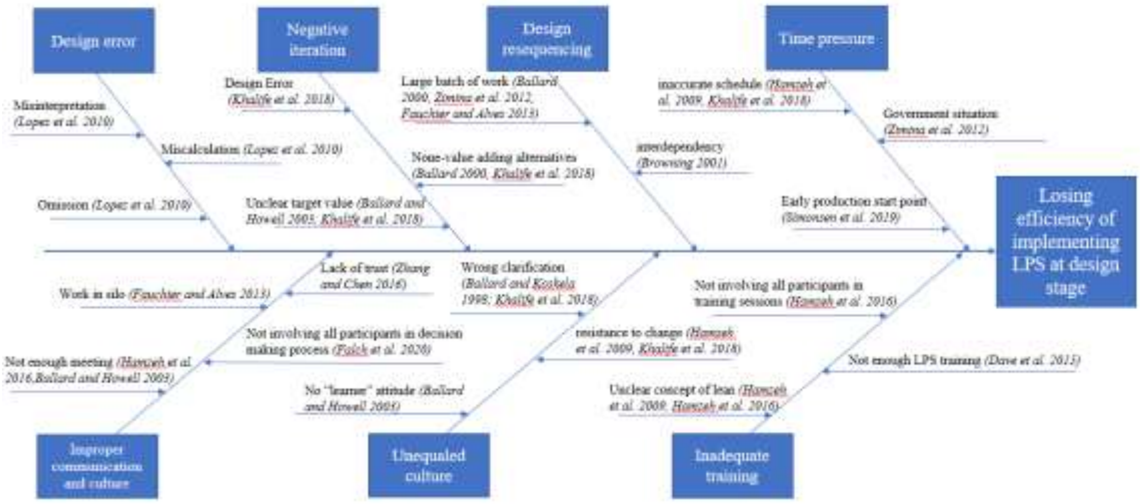

Figure 3: Cause-and-effect diagram.

After achieving data from reviewing previous research and conducting the interview, we mapped the whole design process for a better understanding of all the effective factors on the design process during implementing LPS. In this research, based on the data achieved from previous studies, the interview and process mapping, a cause-and-effect analysis is generated to better identify possible events that negatively impact the implementation of LPS, as shown in figure 3.

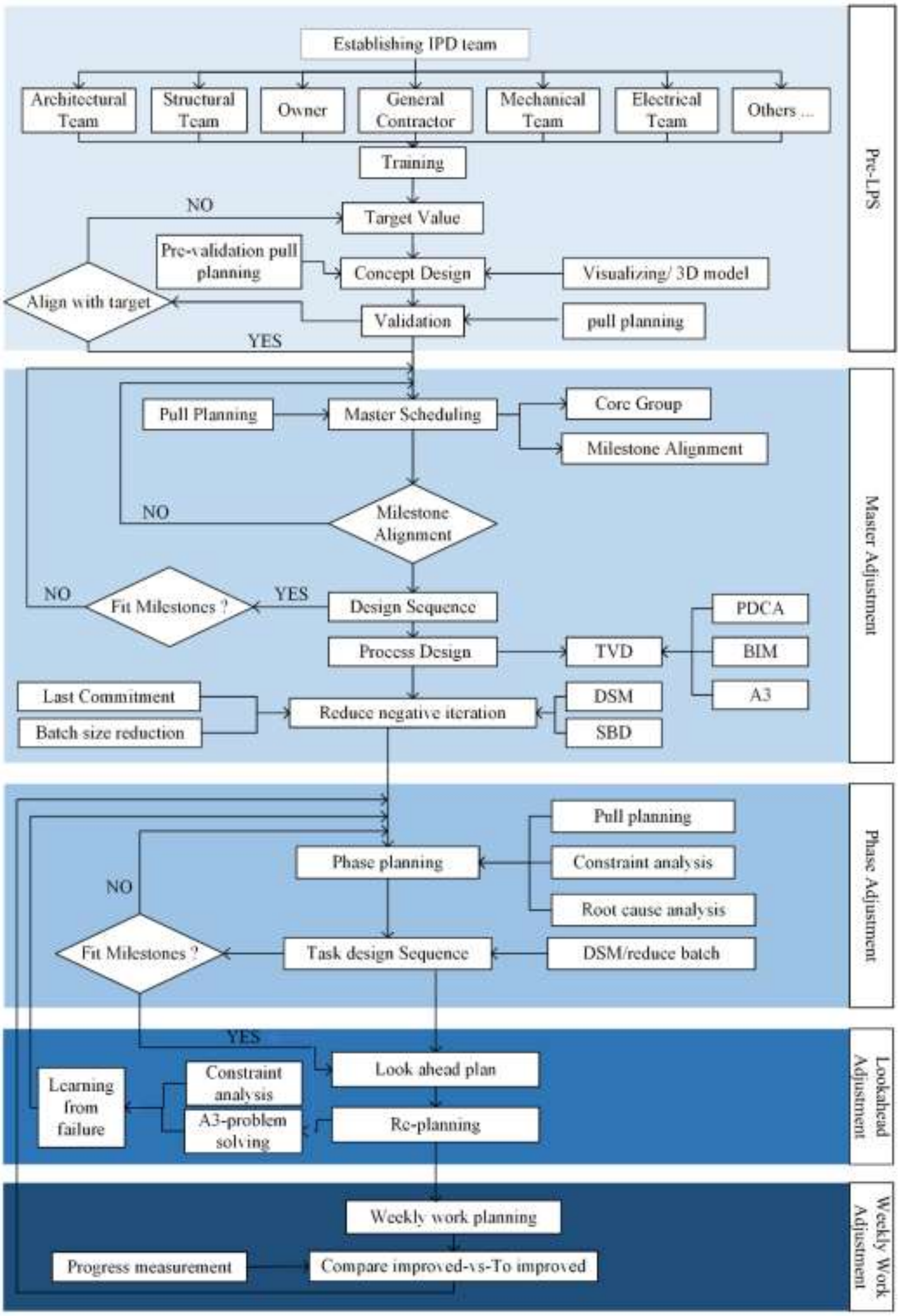

Figure 4: Five stages of the proposed framework.

PROPOSED FRAMEWORK

After gathering and analyzing the data from previous studies and interviews with experts, a framework consisting of five stages was developed to address the current problems of LPS at the design stage in IPD projects (Figure 4). The framework consists of the five stages explained below.

Pre-LPS

Setting up adequate training at the beginning of any IPD project is necessary to build lean culture and prevent creating new problems. Training was found to be useful for motivating project participants, who may tend to be resistant to shifting to a new system. Introducing LPS training and lean construction philosophy to all employees can help build a better lean culture (Hamzeh et al., 2016) and resolve cultural constraints in using LPS in design.

Therefore, in this framework, a pre-LPS stage is used, which is introduced immediately after forming the IPD team. After performing lean and LPS training and before initiating concept design, target value should be defined. Target value aims to make a client value a driver for design. These values can be significant design criteria, budget, schedule, or constructability (Tauriainen et al, 2016).

In developing concept design, 3D models and Building Information Modeling (BIM) can significantly improve the quality of communication and engagement level. Also, in early project stages, before master scheduling begins, pull planning needs to be implemented with rough design information. Pull planning session is another tool used in LPS that has been found to be very useful in improving communication and collaboration. Fosse and Ballard (2016) implemented the LPS method in a case study in the initial design phase and they achieved effective collaboration and transparency.

After developing the concept design, a validation process should be implemented to assure that the design concept is aligned with the target value. Likewise, a pull planning session should be conducted during the validation to improve the applicability of LPS. It will be very beneficial if a lean coach or champion works with the IPD team during the whole project.

Master Adjustment

at the master scheduling stage, milestones and their deliverables will be defined. This process should be done through ‘milestone alignment’ and considering participants' perspectives to minimize priority changes during the design process.

Milestone alignment, proposed by Hamzeh et al. (2009), is conducted during master scheduling and can help reduce changes in priorities. In milestone alignment, perspectives from different participants are considered and aligned for each milestone. Internal and end-users of each milestone are identified, and the output of each milestone is identified (Hamzeh et al., 2009). Milestone alignment is a crucial part of LPS, and correct implementation can significantly reduce the priority changing and increase the consistency of the workflow.

At this stage, pull planning also should be done by the core group containing the seniors of each team. After defining the milestones, the master schedule should be checked to ensure that all the milestones are aligned. After defining the milestones, the design sequence at the high level should be done by considering the alignment with the master schedule. Once the design sequence is determined, the design process will be started and be monitored through a Target Value Design (TVD) meeting. TVD meeting is a good approach in improving the communication and collaboration among the team. This method aims to satisfy or even exceed the client’s expectations by defining and considering all the client’s values such as design criteria, completion date, cost, and constructability (Zimina et al., 2012). Also, some different lean tools and techniques can be used in TVD and increase productivity such as; set-based and evidence-based design, A3 reports, Last Planner, PDCA (Zimina et al., 2012).

PDCA “Plan-DO-Checked-Act” is one of the useful quality management methods in lean construction and can be a good example of the importance of trust (Zhang & Chen, 2016). PDCA is linked with trust-building as it is; *Planning* by forming and maintaining reliable promises across a siloed organization, *Doing* in a predictable and transparent environment, *Checking* approaches and learning, and *Acting* together (Fauchier & Alves, 2013).

For reducing the none-value-adding design iteration, we suggest that from the beginning of the design process, the IPD team gets familiar with the available techniques for minimizing these negative iterations. Then based on the project situation, the most suitable approach can be selected and implemented.

In this regard, Ballard (2000) suggested first minimizing the iterative loops by Design Structure Matrix (DSM). DSM is one of the valuable methods for optimizing the design sequence. DSM visually represents the interaction and interdependency of different levels in a complex system and proposes innovative solutions (Browning, 2001).

After conducting DSM, Ballard (2000) recommended to select the suitable technique from the available options, which are: 1) team problem solving, 2) cross-functional teams, 3) shared range of acceptable solutions 4) share incomplete information 5) reduced batch size, 6) team pull scheduling, 7) concurrent design, 8) deferred commitment, 9) least commitment, 10) set-based vs point-based design, 11) overdesign.

Among the mentioned techniques, Set-based-design (SBD) as a Toyota design approach identifies the available design space and the functional requirements, then it adds input from different disciplines to narrow down the number of concepts to move towards a final design (Sobek et al., 1999). This method can help to keep the positive iteration and minimize the negative one through defining the boundaries for design suggestions, also SBD systematically shares information, which is a crucial feature in the design process (Busby, 2001). Conducting the appropriate techniques at the right time and including the right participants can be advantageous to remove the design constraints in LPS.

Phase Adjustment

after defining milestones, the next stage in LPS is Phase planning. Moreover, pull planning at this stage for each milestone, constraint recognition, and root cause analysis should be implemented to precisely complete this section and make it ready for the next step. These approaches in phase planning help to prevent workflow interruption during the design stage.

For reducing the negative impact of the interdependency in the design process, during design sequencing one of the available techniques or combination of them should be used based on the project situation. To minimize task resequencing, reducing the batch size and using DSM techniques can be very beneficial. This helps in reducing the need for resequencing the design task in the future.

After task sequencing at the phase planning stage, they should be checked to see if they are in line with milestones in master scheduling or not. To achieve a successful LPS in design, it is very important that the master scheduling and phase planning are connected. In case they are not aligned, it is required to go back to the beginning of phase planning and sequencing the task in a way that they fit milestones.

Lookahead Adjustment

After phase planning, the next stage in LPS is lookahead planning. All the related participants should involve in this phase, and they should share their perspectives to be sure everything will be ready for weekly work planning. Re-planning is an unavoidable part of Lookahead Planning. During re-planning, A3 problem solving, or constraints analysis should be conducted to analyze the failure, learn from it, and try to prevent it from happening again in the future. It is very important to consider the lesson learnt at the beginning of future phase planning to have a continuous improvement loop during the whole project.

Weekly Work Adjustment

The last stage of the LPS is weekly work planning, which involves all design team members. In this stage, participants know about their upcoming responsibilities and measurements of progress are taken and compared. Therefore, in weekly work planning, percent plan complete (PPC) and a comparison between *improved* versus *to be improved* should be executed and the achieved results should be considered in phase planning for the next step.

Identify failure and learn from the mistakes in the weekly work planning session can also improve communication by helping participants recognize failures and learn instead of focusing on blame (Ballard & Howell, 2003).

Understanding the constraints and predicting them before they occur plays a crucial role in implementing a possible solution to prevent or reduce them. Hence, learning from previous case studies and planning for failures and successes as part of the design process can be very beneficial.

This framework integrates most of the available techniques, tools, and approaches that can reduce the impact of the design constraints in implementing LPS during the IPD project. Although this is not an exhaustive framework, it can help practitioners to anticipate possible constraints that they might be faced during the design process and be aware of available solutions for them at each level.

CONCLUSIONS AND FUTURE RESEARCH

This research aims to investigate the challenges and constraints of the design process, which reduce the efficiency of implementing LPS in IPD projects and consequently propose an integrated framework for that. Data of this research has been gathered from studying and analyzing literature review and conducting a set of interviews with the experts in this field. In this study, relevant main constraints have been categorized into five different groups: 1) changing priority and design task resequencing, 2) error and negative iteration, 3) lack of communication and the right culture, 4) lack of proper training, and 5) time pressure. After analyzing the negative impact and available solutions for each category, it is found out that the design constraints are interdependent and leaving one constraint unsolved might cause creating other constraints. Therefore, an integrated framework in five phases has been formed to address the mentioned problems. These steps contain pre-LPS, master adjustment, phase adjustment, lookahead adjustment, and weekly work adjustment. The outcome of this research demonstrates that there is no single answer for addressing the design issues. Multiple strategies need to be implemented in an IPD project to optimize LPS at the design stage.

Further studies are required to investigate each category of design constraints in depth, as well as analyze the outcome of using available tools and techniques in preventing or reducing the design constraints.

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