DESIGN PROCESS PLANNING AND CONTROL: LAST PLANNER SYSTEM ADAPTATION

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ABSTRACT

Many companies are seeking to improve their design process through the application of lean principles. However, to implement lean concepts effectively, companies must first achieve basic design process stability by controlling variability and increasing reliability, which the Last Planner System (LPS) helps to accomplish. This study aims to better understand the application of the LPS in design and to propose an adaptation for the design of prefabricated steel construction systems for fast projects, through a case study carried out in a steel fabricator company. This research work was divided into three main stages. First, LPS was applied with two design teams, and an adaptation of the LPS for the specific context of the company was proposed. Second, the refined LPS was implemented in four additional design teams. Finally, an evaluation of the implementation process, based on a set of design planning and control practices was conducted, and a design planning and control model was proposed. The main impacts of the implementation were an increase in process transparency, stronger commitment in the delivery of packages, and collaborative decision-making. The paper also discusses some of the difficulties in terms of implementing medium-term planning, due to the complexity of the process.

KEYWORDS

Design process, planning and control, Last Planner System

INTRODUCTION

Appropriate design process planning and control is essential to support downstream processes, especially in the context of projects that are fast and complex, where design and production occur mostly simultaneously. Planning is also important to support the close interdependency among different design disciplines, especially when the deadlines for meeting client requirements are short. Ballard and Koskela (2002) suggest that the simultaneous execution of design and production currently generates difficulties for managing the design process. Hence, many construction companies are seeking to improve their design process by using lean production principles, such as those incorporated in the Last Planner System (LPS) (Ballard and Howell 1998). However, appropriate implementation requires that companies achieve basic process stability. Such basic stability reduces the variability of the processes,

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increasing their reliability and the availability of resources, producing systematic and coherent results through time (Liker and Meier 2007).

The aim of the Last Planner System (LPS) is to plan and control production and workflow, moving the focus away from individual workers and placing it on the workflow that connects them. This production control system can be understood as a mechanism of transforming what must be done into what can be done, through the identification and removal of constraints in the medium-term plan. It also supports collaboration among people who will execute the tasks in developing plans, and it enables the establishment of an inventory of tasks ready to be undertaken, which will constitute the weekly work plan (Ballard 2000). At the short-term planning level, commitments are made in weekly meetings, from which two indicators can be obtained: (a) Percent Plan Completed (PPC), a planning reliability indicator addressing the the number of tasks completed divided by the total number of tasks planned, expressed as a percentage; and (b) causes for the non completion of tasks.

According to Reinertsen (1997), when several design projects need to be managed simultaneously (a design factory), the inventory of uncompleted design tasks (design in progress) tends to be high. This is due to the fact that design only adds value to the client when finished, as well as due to ineffective control of work in progress. Reinertsen (1997) points out three important design factory characteristics: (a) the management of requirements plays a key role for preventing rework, since these become available along the design process; (b) design activities are not repetitive, and much variability exists in that process, making it difficult to achieve reliability in design; (c) design work tends to expand according to the available time, which may lead to delays in delivery. In addition, there are many external constraints to a project, which do not depend on the designers, increasing the complexity of decision-making (Wise, 1984). Furthermore, according to Ballard (2002), design management tends to overlook production, focusing on concluding tasks, and relegating value generation and flow management to a second plan.

Fabro et al. (2011) presents a case study on the implementation of LPS at building sites, developed with the same company as the case study here reported. The need to achieve process stability in the other departments of the company was evidenced by the work. Fabro et al. (2011) identified delays in the delivery of design stages, as well difficulties in identifying and analyzing design constraints. Hence, the main goal of this paper is to contribute to the planning and control of the design process, helping to achieve the basic process stability in the design department, and to propose a design planning and control model. In order to do that, an adaptation of the LPS was proposed for fast and complex steel projects, which are developed by multiple teams and analyzed as a design factory.

RESEARCH METHOD

This study was developed through a partnership between the Federal University of Rio Grande do Sul and a Brazilian company specialized in the design, fabrication, and assembly of steel structures. The research strategy adopted was Design Science Research, in which a phenomenon/ practical problem is analyzed to enable the design scientist to create an artifact to solve that practical problem (Holmstrom et al 2009). Diverse sources of evidence have been used, including interviews, participant observation, and analysis of existing metrics.

The first step of the investigation was to identify and understand a relevant practical problem. Therefore, an exploratory study was carried out in which data was collected to better understand the context and identify improvement opportunities in existing design planning practices. The second step was to conduct a two-phase empirical study. In the first phase, LPS was implemented with two design teams. In the second phase, adaptations to the LPS were proposed and a production planning and control (PPC) improvement program was performed at the company. Following, the adapted LPS was implemented with four further design teams. In the third phase, an evaluation protocol was applied. The protocol was based on the model proposed by Bulhões and Formoso (2005), in which evaluation criteria are set for fourteen planning practices. That enabled the evaluation of the maturity level of the planning system implemented, and informed the cross case analysis. Finally, a design planning and control model for fast and complex steel projects was proposed. An outline of the research method is presented in Figure 1.

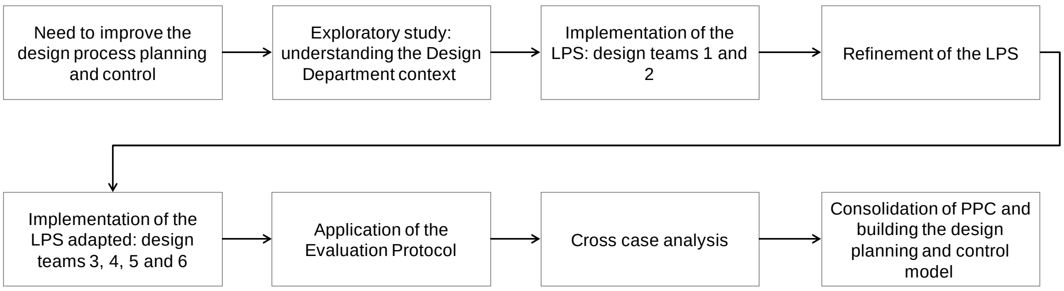

Figure 1: Outline of the research design

OVERALL DESCRIPTION OF THE COMPANY

The company specializes in steel construction systems, acting in Brazil and in other countries. Typical projects include warehouses, supermarkets, factories and shopping centers. The steel structure production process usually has short lead times: the assembly process on site typically starts two months after the start of the design process, and the detailed design stages are developed in parallel with the production of components in the manufacturing plant. The design process tends to be complex due to the large amount of projects being developed simultaneously (on average 75 projects), as well as because of the uncertainty in downstream processes, e.g., changes in deadlines demanded by the client, delays in previous construction tasks, and design changes requested by the client.

Figure 2 provides an overview of the Product Development Process (PDP), which includes the identification of clients' requirements, design development, the production of steel parts, and assembly of the structures on the building site. Different departments are involved in the process: Sales, Cost Estimating, Planning, Engineering Design, Manufacturing and Assembly. The Planning Department produces long-term plans, which are used by all the other departments in the company.

The empirical study was conducted at the Engineering Design department. It comprises of ten design teams, with approximately 15 members each. Four of them are specialised in Conceptual Design, and six in Detailed Design (Figure 2). This configuration was adopted in November 2012. Until then, each team developed the design of the project from start to finish. The restructuring of the teams was an attempt to better define the focus of the teams in the different stages of the design, as suggested by the Design Coordinators.

The Conceptual Design stage consists of the initial conception and definition, generally lasting for about three weeks. It has a great degree of uncertainty and active participation of the client. The Detailed Design phase (lasting 12 weeks on average) is developed in parallel with the production of the steel components and, sometimes, with the assembly process at the construction site. Structures and roofing are detailed and delivered in batches for the Manufacturing Plant and for assembly on site. Design batches include building modules (defined during initial design), and can include: grouting, main structure, secondary structure, walls and roofing systems.

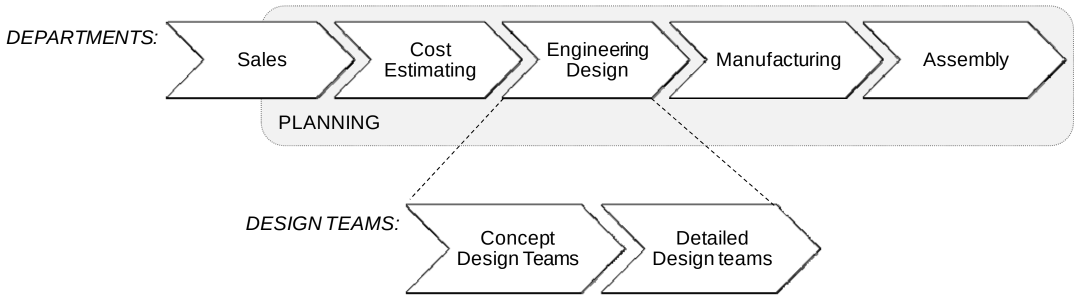

Figure 2: Company's main departments and design teams

CASE DESCRIPTION

Stage 1

The empirical study started with Design Team 1 (DT1) on May 2012. The goal was to understand the configuration of the team and the design types developed. There were no planning routines in use and the Design Coordination (DC) was responsible for planning, with little participation from the designers. Control was practically inexistent, with design deliverables defined with a basis on the long-term schedule. There was no data analysis or learning from what was executed. The study was conducted through weekly participant observations of the short-term planning meetings in June and July 2012 (8 weeks). Due to a restructuring of the Engineering department, the observant participation was suspended in August and started again from October until December 2012 (13 weeks in total).

The researchers then implemented LPS with Design Team 2 (DT2). Data collection started in July 2012. The weekly participant observation in short-term meetings occurred from August to December 2012 (21 weeks in total). DT2 had started using some LPS practices in December 2011, such as the weekly commitment meetings, monitoring PPC and the causes for the non-completion of work packages. However, DT2 did not have a learning routine with the performance measurers; neither did they provide feedback to the overall company design planning and control process.

During short-term planning meetings, the teams planned the work packages to be executed each week and a weekly commitment was made. Reasons for the non-completion of work packages were recorded. Afterwards, the medium-term planning with a horizon of one month, to be updated monthly, was proposed in order to undertake constraints analysis.

Stage 2

The LPS implementation was refined based on the experience with DT1 and DT2. Furthermore, the company decided to start a training program for all design teams on design planning and control. In that program, four additional design teams implemented the adapted version of LPS. Two of them were in charge of Conceptual Design (DT3 and DT4) and the other two were specialized in Detail Design (DT5 and DT6). The research team carried out participant observations in weekly short-term meetings with the above teams took place from December 2012 to January 2013 (5 weeks in total).

At this stage, the teams started to identify backlog activities for each week. Also, further refinements were proposed for fast and complex steel projects: (a) the template used for short-term planning was simplified; (b) unplanned activities held during the week started to be recorded; and (c) constraints began to be controlled in the short term plan, because many of them could only be removed throughout the week due to uncertainties in the design process. Because of those uncertainties, the researchers suggested updating the medium-term plans every two weeks, to make possible a more effective constraints analysis, thus increasing the plan reliability.

EVALUATION CRITERIA FOR THE IMPLEMENTATION OF PLANNING PRACTICES

Evaluation criteria were defined for fourteen planning practices, as presented in Table 1. These enabled the evaluation of the maturity level of the planning system as implemented at the company.

Table 1: Planning practices (adapted from Bulhões and Formoso, 2005)

PLANNING PRACTICES	
Short-term plan	
1	Short-term meetings routine
2	Correct definition of work packages
3	Inclusion of Work Packages without constraints in the Short-Term Plan
4	Backlog of activities scheduling
5	Participant Decision Making in the Short-Term Meetings
6	Performing Corrective Actions based on the Causes of non-completion of plans
Medium-term plan (lookahead)	
7	Look-ahead planning routine
8	Systematic Removal of Constraints
Long-term plan	
9	Elaboration of a Transparent Long-Term Plan
10	Use of Indicators to Evaluate Compliance with the Master Plan
11	Systematic Evaluation of the Master Plan to Reflect the Status of the Works
General: Production Planning and Control	
12	Formalization of the PPC Process
13	Critical Analysis of the LPS indicators
14	Use of Visual Devices to Disseminate Information

The results include an analysis of the degree of implementation efficacy, where a grade is attributed to each practice, as presented in Table 2. In an attempt to avoid neutral responses, researchers suggested four grades.

Table 2: Indicator for the implementation efficacy of planning practices

Degree of implementation	
Implemented	1
Partially implemented	0.75
Barely implemented	0.25
Not implemented	0

RESULTS

The cross analysis focused on the Percent Plan Completed (PPC) and reasons for non-completion of planned tasks. Table 3 describes the number of weeks analyzed per team, the average PPC per team, as well as the main reasons for non-completion. Although the study started in June, for DT1 only the data from October onwards was considered, as that was when the basic short-term routines were understood by the design team.

Table 3: Short term production control data

Design teams	Design phase	Number of weeks	Average PPC	Main reasons for the non completion of work packages
DT1	Detail design	22	76%	Time for completion of activities underestimated (21%); Client related uncertainty (17%); Delay in design approval by the client (17%)
DT2	Detail design	30	78%	Change in design requested by the client (24%); Time for completion of activities underestimated (18%)
DT3	Conceptual design	5	64%	Change in teams' priority (19%); Client related uncertainty (19%)
DT4	Conceptual design	5	61%	Time for completion of activities underestimated (19%); Change in design requested by the client (13%)
DT5	Detail design	5	68%	Time for completion of activities underestimated (24%); Change in design requested by the client (18%); Client related uncertainty (18%)
DT6	Detail design	4	78%	Unavailability of design tool (25%); Delay in the delivery of conceptual design (16%)

DT 1, 2, 5 and 6, which focus on detailed design, had an average PPC between 68% and 78%. DT 3 and 4 had an average PPC of 64% and 61%, respectively. This result is possibly due to the nature of conceptual design, where design decisions are being developed, and where the client has a more active participation in the process. Hence, an improvement opportunity is identified here, which is to make the process clearer for the clients, with the aim of improving the management of their requirements.

The main identified reason for non-completion of planned tasks was planning errors (underestimated time for developing the activity), representing 18.5% of the identified causes (Figure 3). Clearly, designers face difficulties in estimating the duration of their activities. However, this tends to improve with time, when learning occurs through planning. Other significant reasons were design alterations by the client and client's uncertainty, with 15.7% and 14.2%, respectively. These confirm what had been identified through the PPC analysis (Table 3), namely that the client has an important role in the design development process. Hence, there is a clear need for greater client involvement with and understanding of the initial stages of design as well as the sign outs required.

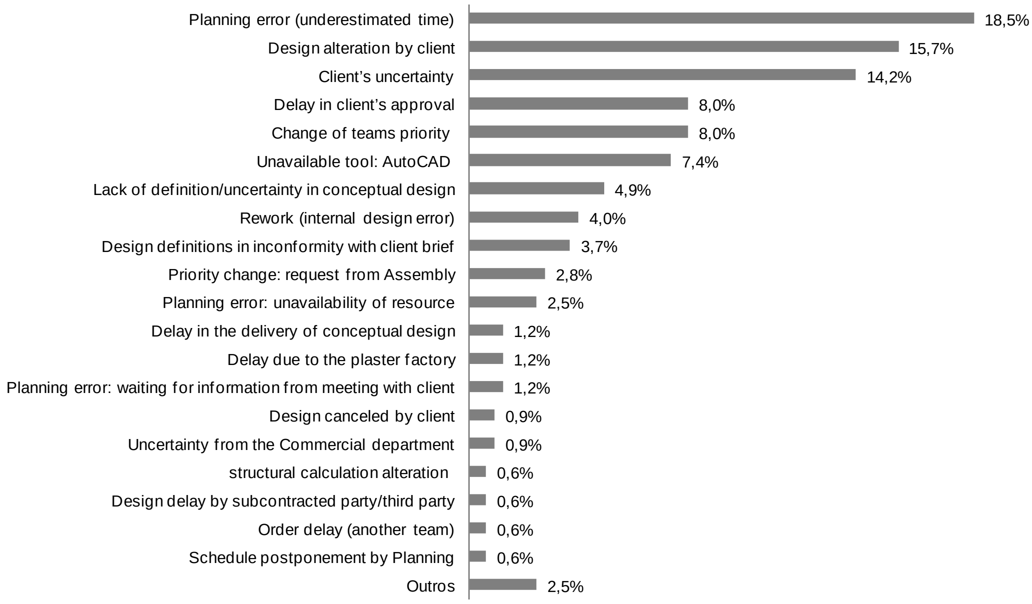

Figure 3: Reasons for non-completion of planned tasks

Reasons for non-completion were classified as: (a) team's internal reasons, predominantly related to underestimated time for the execution of the planned tasks and changes in priorities; (b) company's internal reasons (but external to the team), related to the unavailability of AutoCAD tools, evaluations requested by other departments in the company and delays in the conceptual design; and (c) reasons external to the company, related to client's alterations and uncertainty about design, as well as delay in design approvals. Figure 4 demonstrates that 37% of the reasons are external, 35% are internal to the team and 28% are internal to the company. Despite the higher rate of external reasons, there is a certain balance between internal and external reasons. This is different from what is identified in site planning (physical construction site) for the company, where external causes represent around 80% of the identified problems (Bulhões and Formoso, 2005).

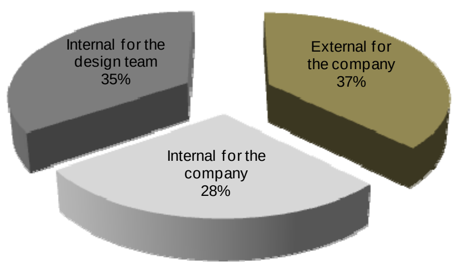

Figure 4: Classification of reasons for non-completion of plans

EVALUATION OF THE IMPLEMENTATION OF PLANNING PRACTICES

Table 4 presents the assessment of the implementation of planning and control practices. The degree of implementation of short-term plans was the highest (77.1%). "Correct definition of tasks" and "participant decision-making in the short-term meetings" stood out, with 100% implementation. The implementation rates for the "short-term meetings routine" and the "backlog of activities scheduling" were also high, with 95.8% and 83.3% respectively. This evidences improvements in the communication between design team members, which contributes for aligning design activities carried out by different people, establishing priorities, collaborative decision-making and stronger commitment with what has been planned. By contrast, teams had difficulty in "performing corrective actions based on the reasons for non-completion of tasks", which plays a key role in terms of learning. Teams also had difficulties related to the "inclusion of tasks without constraints in short-term plans" due to the lack of a well-structured look-ahead process.

Table 4: Evaluation of planning practices implementation

	PLANNING PRACTICES	Teams						Implementation Efficacy	
		DT1	DT2	DT3	DT4	DT5	DT6		
	Short-term plan	Detailed	Detailed	Concept	Concept	Detailed	Detailed		
1	Short-term meetings routine	1	1	1	0,75	1	1	95,8%	77,1%
2	Correct definition of tasks	1	1	1	1	1	1	100,0%	
3	Inclusion of tasks without constraints in the short-term plan	0,75	0,75	0,75	0,25	0,75	0,75	66,7%	
4	Backlog of activities scheduling	0	1	1	1	1	1	83,3%	
5	Participant decision making in the short-term meetings	1	1	1	1	1	1	100,0%	
6	Performing corrective actions based on the reasons why planned tasks were not done	0	1	0	0	0	0	16,7%	
	Medium-term plan (look-ahead)								
7	Medium-term planning routine	0,75	1	0,25	0,25	0,75	0,75	62,5%	58,3%
8	Systematic removal of constraints	0,75	0,75	0	0,25	0,75	0,75	54,2%	
	Long-term plan								
9	Making a transparent long-term plan	0,25	0,75	0,25	0,25	0,25	0,25	33,3%	61,1%
10	Use of indicators to evaluate the compliance with design delivery deadlines	0,75	0,75	0	0	0,75	0,75	50,0%	
11	Systematic updating of the master plan to reflect the status of the works	1	1	1	1	1	1	100,0%	
	General: Production Planning and Control								
12	Formalization of the PPC process	0,25	0,25	0,75	0,25	0,25	0,25	33,3%	16,7%
13	Critical analysis of the LPS indicators	0	0,75	0	0	0	0	12,5%	
14	Use of visual devices to provide information	0	0	0	0	0	0,25	4,2%	
	General adequacy of the model	53,6%	78,6%	50,0%	42,9%	60,7%	62,5%	58,0%	

Implemented (1) - Partially implemented (0,75) - Barely implemented (0,25) - Not implemented (0)

Table 4 shows that the long-term plan had 61.1% implementation effectiveness, particularly the "systematic updating of the master plan to reflect the current state of the works". This is done, whenever necessary, at weekly meetings with the Planning department, when the current state of the designs and the works under way in the company are aligned. The company needs to aim at improving the practices for "making a transparent long-term plan" (33.3%) and the "use of indicators to evaluate the compliance with design delivery deadlines" (50%), particularly in the conceptual design teams, where control is inexistent.

The implementation of the medium-term plan reached 58.3% effectiveness, confirming the designers' difficulty to "systematically remove constraints" (54.2%), despite the attempt of the "medium-term planning routine" (62.5%). The removal of constraints identified at the medium-term planning enables a production protection mechanism, creating favorable conditions for the continuity of the team's activities and, hence, process stability. Although the identification of constraints was supposed to be made at the medium-term plan level, the removal of constraints was discussed in the short-term planning meetings, as main of the issues identified could only be removed in the horizon of a week.

The general practices related to the planning process presented the lowest index, 16.7%. Thus, the need to "formalize the PPC process" (33.3%) is evident, since only the short-term plan has been standardized. In order to do that, the "use of visual devices to provide information" (4.2%) is considered essential as it contributes to the implementation of other planning practices.

The overall implementation adequacy was 58%, which represents an average of the percentage of implementation of each planning practice by all teams. DT2 obtained the highest score, 78.6%. This is possibly due to the strong commitment of the team with implementation, especially with the Design Coordinator's participation in the planning meetings, which was crucial for the other members to acquire a critical view. Differently from the other teams, DT2 seek to "perform corrective actions based on the causes of non-completion of planned activities", through a monthly cycle of discussions and learning through the "critical analysis of the LPS indicators". The other teams, lacking the group analysis of the LPS indicators, obtained scores of 50% to 62.5%.

INTEGRATED PLANNING AND CONTROL MODEL FOR DESIGN

Based on the application and refinement of the LPS in the context of a complex and fast design process environment, a design planning and control model was proposed. The Planning department, responsible for the long-term plan, plays a fundamental role in the Integrated Planning between the different departments of the company. Consequently, in the proposed model the Planning department should focus on achieving the company's monthly design targets. Therefore, it is important to balance the workload between the different design teams, particularly in the integrated design medium-term planning (when the external constraints to the teams can be analysed). Based on that, each design team can more easily meet their weekly short-term goals, as well as their medium-term goals every month (updated every two weeks). This model, still under development, is presented in Figure 5, which includes: (a) integrated medium-term plan meeting, a weekly meeting among a representative of the Planning department and the Design Coordination's, when the external constraints to the teams can be analyzed; and (b) weekly short-term/medium-term plan meeting, when the internal constraints to the teams are analyzed.

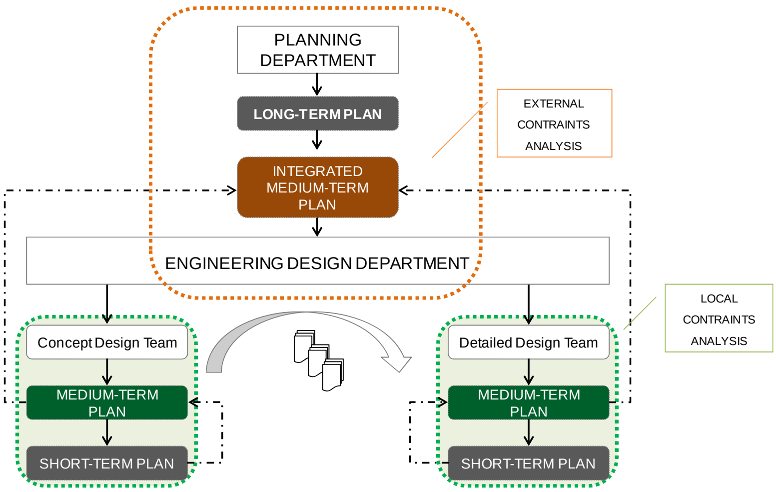

Figure 5: Proposed design planning and control model

CONCLUSIONS

The goal of this study was to contribute to design process planning and control by adapting the Last Planner System to an environment with fast and complex steel structure designs, formed by multiple teams, characterizing a design factory. Through the application of LPS in six different design teams, and the evaluation of the degree of implementation of fourteen planning practices, it was possible to refine the model and point out its main benefits, as well as to identify improvement opportunities in its implementation.

The main benefits of the proposed model are the increase in process transparency, improved workflow, stronger commitment and collaboration among design team members, increasing predictability and flexibility in decision-making, as well as compliance with the schedule. It also enabled the design planning and control process to be better integrated with production planning and control at the manufacturing plant and assembly on site.

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