CONTRIBUTIONS FOR THE INTEGRATION OF DESIGN AND PRODUCTION MANAGEMENT IN CONSTRUCTION

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Abstract
Product Development Process (PDP) has become an important research topic in construction since the 80's. However, there are few research efforts focusing on understanding the integration between design and production planning and control. This paper discusses how to plan and control the design process in construction through the use of the Last Planner System. It is based on four case studies carried out in industrial and commercial building projects. The main proposition of this investigation was to adopt the Last Planner System for the design process and to explore links between design and production management on site. Both quantitative and qualitative data were collected. The main conclusion of this study was that the Last Planner System provided some key support for integration of design and production management on site.

Keywords: Design management, last planner system, product development process.

INTRODUCTION
Until the 80's design was often mentioned in the literature as a small part of the research and development (R&D) function[3] of firms or as a supporting activity for manufacturing. However, design has grown in importance due to the continuous increase of the complexity of products and due to changes in the market. This evolution has demanded more integrated approaches to the PDP, especially in global, intense and dynamic competitive environments. According to Prasad (1996) and Koskela (2000), concurrent organisation of product development emerged in the mid 80´s aiming to reduce project lead-times as well as to improve products from the point of view of both internal and external customers. For that reason, the implementation of concurrent engineering (CE) has been widely reported in several industrial sectors, such as aerospace and automotive. In the construction industry, this trend has helped some market segments (e.g. the commercial and industrial building sector) to achieve better results, although the complexity of project management has been increasing.

The difficulties of managing processes have increased the importance of developing research related to planning and control. In construction, the Last Planner System, developed by Ballard and Howell (1998), has been successfully applied to the management of production in different countries. Despite its positive results in production, only a relatively small number of studies have been undertaken on the application of the Last Planner System to the design process (e.g. Miles, 1998; Tzortzopoulos et al., 2001). However, those studies have not explored the integration between the design and production planning and control processes. This paper discusses how to plan and control the design process in construction through the use of the Last

[3] A function (in organizational terms) is an area of responsibility usually involving specialised education, training, or experience. The traditional functions in product development organisations are marketing, design, and manufacturing (Ulrich and Eppinger, 2000).

Planner System. It also explores possibilities for integrating planning and control systems used for both design and physical production.

BACKGROUND

Different authors have approached the Product Development Process from different perspectives, adopting different concepts and scopes. For the purpose of this study, PDP is defined as the inter-functional process that starts with the identification of a market opportunity and ends with the analysis of the product's performance in use. The evaluation of the performance in use is necessary to provide feedback to the development team through information that can help improving the team's performance in the development of future products. In this context, the PDP functions cannot be developed separately. This means that, apart from the relations between internal disciplines of each function (e.g. architectural, mechanical and structural design), the inter-relations between functions have to be considered, resulting in a huge and complex process.

Many managerial problems arise due to the complexity of the PDP. Therefore, to manage such a process poses many difficulties, dependent on the type of product, service or company. According to Clark and Wheelwright (1993), this is due to a fundamental problem: managers generally fail to plan skills and resources, to define project proposals appropriately, and to integrate different functions used by the company. Aiming to assist both designers and managers, some initiatives have been developed (e.g. Process Protocol, Analytical Design Planning Technique, Concurrent Engineering and Last Planner System). As the adoption of the Last Planner in fast, complex and uncertain projects constitutes the proposition of this research, both CE and the Last Planner System are briefly highlighted:

Concurrent Engineering: despite a considerable number of publications (e.g. Prasad, 1996; Kamara et al., 1997), CE has still been described as a set of principles and methods. For the purpose of this study, CE is defined as an approach that considers that PDP activities can be developed in parallel, in a simultaneous way. It aims at constantly readjusting the timing of both linear and sequential processes, to make all stakeholders aware of all the activities to be carried out from the start (Prasad, 1996). According to Kamara et al. (1997) CE is very useful in dealing with the problems faced by the construction industry. Those authors also stress that its effective application must consider certain specific construction characteristics (e.g. there are difficulties related to the involvement of all stakeholders at the front-end).

Last Planner System: this system is based on the hierarchical division of planning and control into different decision-making levels (e.g. long, medium and short-term)[4]. Despite problems related to it effective implementation, the utilization of the Last Planner has provided successful results in physical production management and promising results in design management.

In production management the aim of the long-term production planning is to establish production goals, i.e. main process flows and production rhythms. The aim of medium-

[4] The hierarchical division is still a research topic as discussed in Ballard and Howell 2003.

term production planning is firstly to establish a link between the long and the short-term planning levels. Secondly, but not less important, the objective is to identify and remove constraints. In order to do that, the activities must be planned a period of time in advance (e.g. three weeks). In the short-term production planning, the aim is to guide the production process on the construction site. On this level the only activities programmed are those for which constraints have been eliminated and which are within a planning horizon below the medium-term horizon (e.g. one week). The performance of this planning level is measured by the indicator "Percentage Plan Complete" (PPC), which is the quotient between the total of activities fully completed and the total of activities programmed. Causes of non-completion are analysed in parallel.

The suitability of the application of the Last Planner system to design is still under investigation. However, it is assumed that the hierarchical planning levels would be the same, and some general adaptations to design have been proposed. At the long-term, planning should start with the establishment of milestones for the completion of design tasks (Miles, 1998). These milestones should be set according to the sequencing of PDP phases (Tzortzopoulos et al., 2001) or they should be set according to physical production priorities (Miles, 1998). Medium-term design planning should start with detailing the design master plan, considering a planning horizon of a few weeks ahead (Miles, 1998). Important roles of this level of planning are the identification and removal of constraints on time and the planning of the activities that should be carried out in parallel at the short-term level. Although it is considered essential, there are few reported experiences in medium-term project planning. In short-term design planning, the aims are to plan and control the activities that can be undertaken. In order to do that, it is necessary for the people involved to negotiate the activities programmed, to define the responsible parties, to define the deadlines for the execution of the tasks (Miles, 1998).

RESEARCH METHOD

Four case studies were carried out in a medium-sized (approx. 150 employees) construction company located in Porto Alegre, Brazil. This company is usually involved in industrial, commercial and hospital projects. These projects tend to be very fast, complex and uncertain – some of them consist of the refurbishment of operating facilities. In general, the company's responsibility includes managing subcontracted designers through the design process, and managing own as well as subcontracted work force. Despite the company has an established partnership with subcontracted designers, they contract other professionals when suggested by the client.

The following research techniques were used in this research: (**1**) literature review of both theoretical and empirical research concerning PDP management and, planning and control; (**2**) participatory observation of design and production planning and control meetings (in all 57 short-term production meetings; 57 medium-term production meetings; 25 design meetings). The role of the researcher in design and production meetings was to collect data related mainly to decision making. A spreadsheet was used to register the participants, decisions made and problems concerned the use of the planning system; (**3**) site observation of problems occurring due to the poor integration of design and construction, in order to identify the root causes of the problems observed on the construction site. In order to do so, the researcher visited the construction site weekly.

A camera was used to register the empirical evidence; (**4**) 15 semi-structured interviews with managers and designers (02 with production managers and 13 with designers of different disciplines); (**5**) document analysis, e.g. plans and performance of the design and production teams; (**6**) observation of internal seminars (with the research team) and external seminars (involving company managers and supplier representatives).

Data analysis related to design and production integration was based on the identification of design tasks in conducting production planning and vice versa. In relation to the applicability of the Last Planner system for design planning and control, the variables considered were the percentage of design tasks completion, the number of unfinished production tasks due to design problems, and designer's perception of usefulness and utility.

DESCRIPTION OF THE CASE STUDIES

Case Study 1 (CS1)

CS1 involved two industrial projects. The first project was the refurbishment of an existing two-storey building of 831.96 m^2 and a 1,607.05 m^2 extension. The project duration, which was contractually established, was six months for the development of both design and production. The second project, carried out for the same client, was the construction of an industrial laboratory of approximately 400m^2, in which the design was considered to be complete. The contractual duration established for its completion was three months.

In the first project, weekly meetings were held to plan and control long, medium and short-term production as well as short-term design. The participants of the short-term design meetings were construction company representatives, client representatives, all designers and key-suppliers (usually 20 people). The planning was conducted by the construction manager and the plans established with the agreement of all people involved[5]. At the medium-term production meetings, participants included the production manager, selected system suppliers and, when necessary, selected designers and client representatives. Figures 1 and 2 represent the spreadsheet developed for the construction company to plan and control the medium-term production plan.

PORTO CONSTRUCTION COMPANY	LOOK AHEAD PLANNING	Project: Engineer: Foreman:	PERIOD 1 / Date = 25/3/2002 à 9/4/2002	START 25/3/2002 1ª WEEK 13/3/2002
		ISO-100-05	FORMAT	Date: 16/4/2003

TEAM	TASK DESCRIPTION	CONSTRAINTS	START DATE	END DATE	DURATION	OK	WEEK 1							WEEK 2							WEEK 3							WEEK 4						
							13/3/2002 à 19/3/2002							20/3/2002 à 26/3/2002							27/3/2002 à 2/4/2002							3/4/2002 à 9/4/2002						
							13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01	02	03	04	05	06	07	08	09
							W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
					0																													
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Figure 1 – Electronic spreadsheet for medium-term planning

[5] The construction managers were responsible to apply the Last Planner System in all case studies.

PORTO CONSTRUCTION COMPANY	CONSTRAINTS LIST		Project: Engineer:		REMOVAL LIMITE DATE / WEEKS				PERIOD	1	ISO-100-05 Date: 28/02/02
Nº	CONSTRAINT DESCRIPTION		RESPONSIBLE	REMOVAL DATE	13/03 a 19/3 W1	20/03 a 26/3 W2	27/03 a 2/4 W3	03/04 a 9/4 W4	FORECAST COST	OK (Y or N)	PROBLEMS
1											
2											
3											

Figure 2 - Electronic spreadsheet for constraint analysis

Once identified, the design constraints were made clear by the production manager to the designers in the short-term design meetings. The design constraints were split into tasks for designers to carry out. Figure 3 demonstrates an example of the short term plan spreadsheet used in CS1. By the utilisation of this spreadsheet, plans were established in terms of task, time for task development and responsibility for the task. Problems related to task non-completion were also listed.

PORTO CONSTRUCTION COMPANY		WEEKLY DESIGN PLAN	Project: Engineer: Coordinator:	Week no: ___ Period ___/___ to ___/___ PPC: ___ TOTAL: ___							Quality Control No.___ Date: ___/___/___
Resp.	Exec. 100%	Task		Week 1							Problems
				W	T	F	S	S	S	T	

Figure 3 – Design short-term spreadsheet

Figure 4 represents the relationship between the planning and control levels established for the first project.

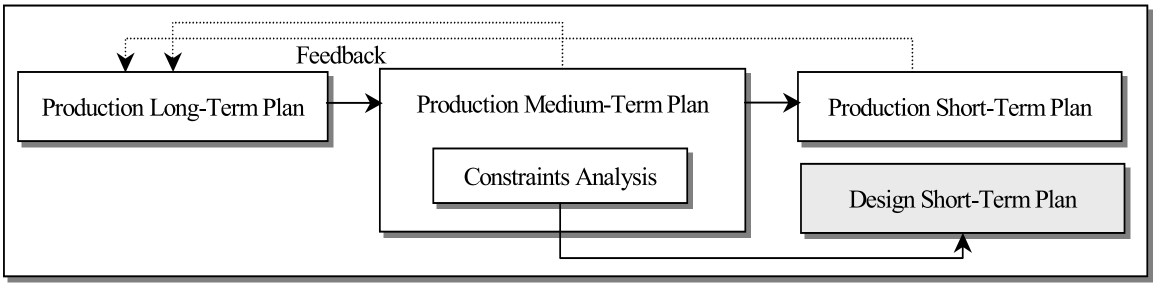

Figure 4 – Relationship between production and design planning levels in CS1

In the second project no design meetings were held. Medium and short-term production meetings were held on a weekly basis.

Case Study 2 (CS2)

CS2 focused on a project consisting of nine buildings on two construction sites near the coast of Rio Grande do Sul, Brazil. In total, these buildings had an area of approximately 6,200m^2 and were designed for the storage of oil pipes and safety training of the client's employees. The duration established for the completion of the buildings was five months. In CS2, the design was considered to be complete, except for the mechanical and electrical (M&E) and pre-cast reinforced concrete structural designs.

The medium and short-term production meetings took place on a weekly basis. Constraints related to design were released to the designers by e-mail or by occasional meetings. The production manager held occasional meetings with each designer separately. Based on the analysis of SC1, the production manager tried to plan the design at a medium-term level. Despite the manager's efforts, the medium-term plan failed because design meetings were held between the production manager and each designer separately, and interaction between different design disciplines could not be facilitated.

Case Study 3 (CS3)
CS3 involved the monitoring of the elaboration of the proposal for the construction of a commercial building of 4,560m^2. The design had been developed under the supervision of an architect hired by the client. In order to reduce production lead-time and costs, various design reviews and alterations were proposed by the construction company.

The planning and control system proposed in this study is represented in Figure 5. As the construction company had not yet been contracted for the production stage, no medium-term or short-term production planning meetings were held. Four medium-term and short-term design planning meetings were held for discussing and reviewing design changes. In CS3, the decision was made to integrate medium and short-term design plans due to the close interaction between design activities observed in previous studies. In the design meetings, short-term design tasks were established and simultaneously constraints related to performing the design tasks were identified, analysed and listed as tasks for designers.

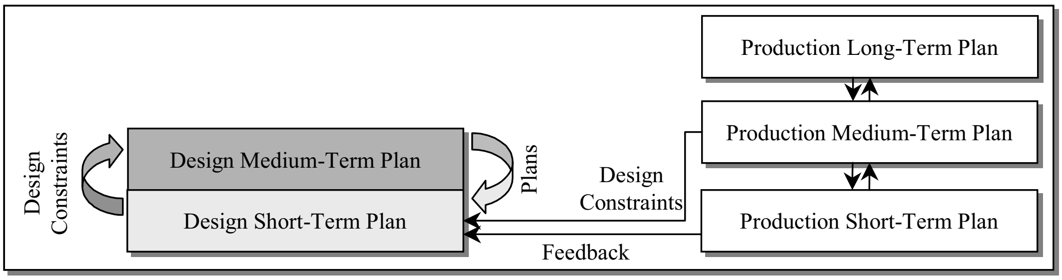

Figure 5 - Planning and control system proposed in CS3

Case Study 4 (CS4)
CS4 involved the execution of two buildings over a 15 month period. The first was a 22,300.00m^2 ten-storey car park building. The second was a 16,450.00m^2 thirteen-storey office building, to accommodate consultation offices, outpatient facilities for different medical specialities, and a cancer care unit. Although the design was completed before the construction company was contracted, it was necessary to make several substantial design changes after the production stage started. The client established a design coordinator to conduct design revisions. Figure 6 illustrates the relationship between design and production planning.

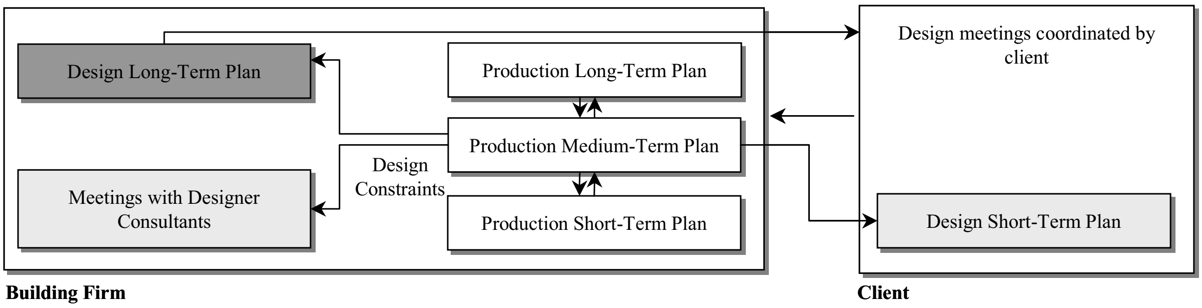

Figure 6 – Relationship between design planning levels for the construction firm and client

In order to avoid delays, the construction manager produced a long-term design plan establishing priorities for the design team. This plan was based on the following decision sequence for each major production process (Figure 7 – read from right to left): (a) the identification of production milestones, (b) the establishment of the lead-time for the supply of the necessary components, as well as the respective managerial activities, and (c) the definition of design milestones.

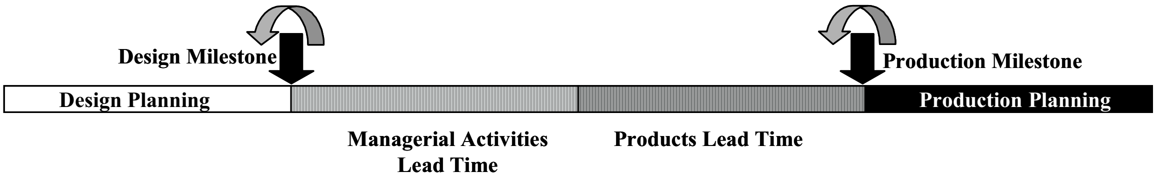

Figure 7 – Criteria for long-term design planning in CS4

Figure 8 represents the spreadsheet developed for the construction company to plan and control the long-term production plan. The designs tasks established on the long-term design plan were broken into smaller tasks by the design coordinator and the designers during weekly design meetings where the construction manager participated. When the time for developing the design tasks was not sufficient, the production manager was consulted about the possibilities to shift the production milestones.

PORTO CONSTRUCTION COMPANY		DESIGN LONG-TERM PLAN				GANTT CHART											
Construction Event	Design tasks	Production milestone (date)	Related lead time (days)	responsible	Design milestone (date)	Jan				Feb				Mar			
						Weeks				Weeks				Weeks			
						1	2	3	4	1	2	3	4	1	2	3	4

Figure 8 – Electronic design long-term planning spreadsheet

RESULTS

The following observations were made concerning the integration of design and production management:

(1) long-term design planning made it possible to identify inconsistent production goals (e.g. in SC4 when the established time was not enough to develop design tasks the production milestones were pushed, generating a more realistic view of the production goals to be achieved);

(2) planning medium-term production planning made it possible to identify constraints related to design[6] and to reduce the number of production non completed tasks due design. Specifically in SC1 21.8% of the causes of the non-completion of the plans were related to design. Most of the problems occurred during the initial three weeks of production when the design was still in development.
(3) short-term design planning made it possible to take into account production requirements in the initial design;
(4) short-term planning and controlling of production made it possible to give feedback from the production to the designers. The causes of non-completion of production tasks were presented to designers in the design meetings;
(5) in SC1, despite the utilization of the Last Planner system for the design and production management, the total concurrency between design and production was not possible. In SC1 the production started four weeks after design had been started. These four weeks were used to improve the design maturity.

Regarding the utilization of the Last Planner System for the design and production management the following observations were made:
(1) the PPC increased as the people involved began to understand the logic of the design and production planning. In SC1, the PPC in design rose from 44% in week 1 to 72% in week 8. In all case studies, the PPC in production increased considerably at the front-end of the production stage;
(2) the involved managers expressed some difficulty in elaborating the short-term design plans and medium-term production plans, however they still considered the results that were obtained satisfactory. The analysis of medium-term production plans and constraints showed that 54% of the tasks were scheduled in week one, 28% in week 2 and 6% on week 3. The rest were related to tasks and constraints identified later and related to the period before week 1 in all cases analyzed;
(3) in projects where design had been considered finished the production manager had difficulties in eliminating design constraints because the design team had been dissolved before the beginning of the production stage;
(4) root causes of non-completion of design tasks were related to the lack of fixed patterns in the information exchange (e.g. different software versions and drawings with a non-established scale);

Finally, in SC1 and SC3 the design was fully developed and delivered on time in the order that was required for production. Although the deadlines were met, in the production phase, however, it was not possible to undertake this analysis, as the data collected bore no relation to meeting the targets.

FINAL CONSIDERATIONS

With the aim of integrating design and production planning and control processes, in this study, we have investigated the possibilities of identifying and defining the information

[6] Constraints related to the design were identified during the whole production stage in all study cases, including those where the design was considered finished. In general, the identified constraints were related to a lack of compatibility between design proposals; unachieved requirements, requested changes in design solutions or to the fact that a specific detailed design had not been done.

requirements for the design in the design and production process. Main contributions are highlighted below:

To completely overlapping the production and design processes was considered inadequate. In this case, the time between the delivery of the design and the start of production must be used to guarantee the maturity of the information made available. The use of small batches of information, recommended by Reinertsen (1997), makes the design process more dynamic. However, planning design activities in small batches of information represents a shift away from the conventional manner in which designers traditionally develop projects (large batches). This may lead to a resistance on the part of designers to use it.

The integration of design planning and control in production management was evidenced through the constraint analysis in the medium-term production planning (where design related production constraints were considered as tasks for designers) and through the analysis of the causes of unfinished work in the short-term production planning. This was also evidenced by the fact that some design solutions were changed to make production deadlines feasible and when production deadlines were changed in the instanced where design tasks demonstrated that the established deadlines were unfeasible. Finally, in terms of design and production planning by adopting the Last Planner System, we have concluded that this is an alternative to the reduction of variability and uncertainty in fast, complex and uncertain construction projects. Similarly to Miles (1998) and Tzortzopoulos et al. (2001), we have observed benefits such as increased efficiency, increased transparency in the design process and increased commitment from the people who are doing the planning. Nevertheless, the use of the Last Planner System for design and production should consider some CE practices such as early team involvement, effective exchange of information and feedback.

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