PLANNING THE PRODUCT DEVELOPMENT PROCESS IN CONSTRUCTION: AN EXPLORATORY CASE STUDY

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ABSTRACT

The emergence of a new production paradigm has been widely discussed in the literature. Concepts developed in operations management research related to the new paradigm should also be valid and useful in construction. Unfortunately, these have been weakly applied in the product development processes in most companies, despite the importance of this process.

The product development process (PDP) comprises the set of activities needed for the conception and design of a product, from the identification of a market opportunity to its delivery to the final client. Its main objective is to translate customer requirements and needs into a design solution. Successful PDP requires the effective control of the work developed by the teams involved and of the exchange of information between them.

This paper aims to contribute to the integration of the existing theories related to product development and operations management, looking for linkages between them. It also presents the results of an exploratory case study that aimed to propose a model for planning and controlling the PDP, based on the adaptation of tools originally developed for physical production planning and control. This involved the implementation of a previously defined process model for managing the PDP, as a basis for long term planning. The main benefits and difficulties faced during the implementation of this planning method are discussed.

KEY WORDS

Product development, process planning, operations management, design management.

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1. INTRODUCTION

Since the late Seventies industrial companies have experienced changes involving all of their activities as a result of a broad range of predominantly organizational and managerial innovations, including Just in Time (JIT), Total Quality Management (TQM), Concurrent Engineering (CE) among others (Bartezzaghi 1999). This process of change has been so radical as to suggest that a new production paradigm has emerged. Womack and Jones 1996 proposed that Lean Production is the practical realization of the new paradigm, but this has been questioned (e.g. Cusumano 1994, Spina et al. 1996, Bartezzaghi 1999). Nevertheless, the emergence of Lean Production has encouraged production to be analyzed as being composed of three core phenomena: product development, order-delivery and production proper (Womack and Jones 1996), all of them focusing on the customer.

It has been widely argued in the literature that there is a lack of consolidation of operations management theory, mostly due to different views and approaches that had emerged over the last thirty years (Koskela 2000, Bartezzaghi 1999). Similarly, design science lacks sufficient scientific foundation and consequently product development has been too much guided by intuition and experience (Koskela 2000). The debate over the replacement of mass production by Lean Production created an opportunity to extend this theoretical basis. This is the purpose of the TFV (transformation, flow and value generation) theory proposed by Koskela (2000), which has been used as the conceptual basis for this research.

Product development is critical for the performance of many companies. The success of product development efforts can determine the viability of companies and economies (Ulrich & Eppinger 2000). Despite its importance, relatively little research has been made on management of the PDP, in relation to the insightful review of experience that has been dedicated to physical production[4] (Austin et al. 1996; Koskela et al. 1997, Reinertsen 1997).

Therefore, it is important to learn from the improvements achieved in ~~the~~ operations management science and transfer successful concepts and principles to product development in construction. The aim is to achieve similar improvements as obtained in manufacturing, such as reduced waste, reduced lead times, and other effects that improve quality, accelerate learning and lower costs. In order to make this transfer effective it is important to consider the nature of product development, and its differences and similarities in relation to physical production.

Many problems related to the quality of the PDP are directly related to the structure of activities and their relationships throughout time. Planning and controlling the PDP is usually developed separately by each design specialty, in an excessively informal manner. Without the consideration of the work that must be developed by other design disciplines, it is difficult to coordinate the schedule and the information flow in a multidisciplinary environment such as design. Moreover, planning is effective when it is matched to available information by establishing different hierarchical planning and control levels (Laufer and Tucker, 1987).

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[4] The term production has been used in the literature both in its narrow (production proper) and broad (product development, order-delivery and production proper) meanings. In this paper, the expression “physical production” is also used for referring to production proper whenever the meaning is not clear fro~~or~~m the context.

This paper discusses a conceptual framework for product development in construction. The evolution of design science is presented, and links with operations management research are depicted. Finally, the results of an exploratory case study are presented, which investigated ways of planning and controlling the PDP in construction.

3. THE PRODUCT DEVELOPMENT PROCESS

Ulrich & Eppinger (2000) define "*Product development* as a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product". These authors stress that it is necessary to bring together the main functions of the enterprise, e.g. marketing, design and manufacturing to achieve successful PDP. Smith & Morrow (1999) and Hales (1993) define product development as the process of converting an idea, market needs or client requirements into the information from which a product or technical system can be produced. Although each PDP is unique, there are common features that are shared between different projects. Understanding what those projects have in common is an important step to guide the management of future product development processes.

The most fundamental difference of product development in relation to physical production is that the value aspect of design is much more significant (Koskela 2000). Table 1 presents some differences between these two processes.

Table 1: Some differences between product development and physical production

PHYSICAL PRODUCTION	PRODUCT DEVELOPMENT
Produces physical goods	Produces information
Lower unpredictability and uncertainty	Higher unpredictability and uncertainty
Repetitive process	One time process
Have standards for how long the work should take	The work expands to fill the available time
The work is either done or not done	It is difficult to determine when the work finishes
Likely to produce learning by repetition	Not likely to produce learning by repetition
Risk and variability must be avoided	Variability (necessary to create value) are desirable in some tasks

Product development is usually a complex process because of the range of technical issues that must be addressed, and also because of the variety of people and organizational structures that must be employed over the life of a product development effort (Smith and Morrow 1999). Product development involves a large number of decisions in a highly uncertain environment. The internal and external uncertainty often pushes the design process away from the best design sequence, resulting in low productivity, prolonged duration and decreased value of the design solution (Koskela et al, 1997).

Due to the nature of the process, it is difficult to assess the amount of completed or remaining work in any design task and consequently, in the project as a whole (Reinertsen 1997, Ballard 2000). In product development, the work tends to expand to fill the available time, because it is always possible to improve design in some way (Reinertsen 1997). As a result, it is not possible to plan the design process as a sequence of well defined steps, since most decisions are affected by some that have been made before and also by others that will be made in future stages of the project. Similarly to physical production, product development should not be planned at a very fine level of detail, since it is a highly unpredictable and uncertain process.

Nevertheless, modelling the PDP process and decomposing it into workflow activities is necessary to organise the work of the product development team and direct its efforts (Prasad et al. 1997). The goals of process modeling are several, including learning about the process, suggesting ways of controlling it, and also developing common goals and understanding of tasks among the members of the project team (Smith and Morrow 1999). However, product development is more difficult to model than physical production processes because of a greater variety; lower number of repetitions, and the high level of human intervention. As a result, PDP modeling is in an earlier stage of development compared to other areas of management science (Smith & Morrow 1999, Reinertsen 1997). The evolution of product development models and its relation with operations management are presented below.

3.1. Evolution of product development models

Koskela (2000) stated that the evolution of design science can be grouped in three categories: craft design, sequential and concurrent engineering. Until the Second World War, products and production processes were simpler, and thus there was little need for specific managerial practices within design. With the diffusion of systematized design methods, due to the development of large-scale systems and the production of weapons after the War, new methods for managing product development emerged (Koskela 2000).

Based on a survey related to the automotive and aerospace industrial sectors, Yazdani & Holmes (1999) proposed four models of design definition, which illustrates the evolution of sequential design towards concurrent engineering.

The first model, named **sequential,** represents the traditional form of product development organization. The methods adopted in this model are functionally oriented with little integration, rather than process oriented. Predominantly, many layers of management are required in this type of organization. This model has not proved to be satisfactory to cope with the emerging industrial pressures, i.e. reduced cost and time and better quality.

The second model, named **design centered**, emerged because the cost of change at each sequential stage was very high, and it became apparent that more life-cycle considerations were demanded. This model does not require a departmental integration, but an understanding of the downstream activities. Downstream design changes are minimized through a higher level of design analysis at the front-end process. The process is still predominantly sequential, but there is a higher confidence in design information.

The ongoing drive to reduce development lead times and the need for more complex products made the task of modeling downstream considerations increasingly difficult. This fact led to the necessity of a greater involvement of downstream activities to bring all specific expertise to the design stage. This initiated the development of **concurrent product definition**. In this model, each stage of product development has a gate attached. Information exchange is facilitated by the introduction of multi-functional teams. Usually there is a matrix style organization related to the concurrent model.

Finally, the **dynamic model**, a further development of the concurrent model, emerged due to the necessity of a much more intense degree of communication between the teams from the start of the PDP. A wide range of technical, business and project management skills are required to enable the project team to make the necessary decisions. Also, a fully dedicated multi-functional project team is required, which results in a very flat organizational model. This model has been only identified in Japanese automotive companies, and it is also referred as “set based concurrent engineering” (Ward et al. 1995).

Some links can be observed between the analysis of the design models presented by Yazdani & Holmes (1999) and the TFV theory proposed by Koskela (2000). The sequential and design centered models are conceptualized as the transformation model of production, in which focus is given to task completion, and the goals of value generation and flow management are often neglected. The transformation principle of hierarchical decomposition is usually applied to manage the PDP. These models tend to result in relatively long cycle times, higher rates of rework and a higher risk of not meeting customer requirements.

One of the major benefits of the concurrent and dynamic models is that the flow and value generating aspects of design are emphasized and thus can be managed. Shortening of product development lead-time was one of the drivers of the emergence of CE. This can be achieved through the elimination of waste related to transfer of information, waiting times, and inspections, as proposed by the TFV theory. Nevertheless, there are no universally accepted definition, basic features and methods of CE (Prasad, 1997). This demonstrates the lack of a conceptual foundation in design science. Furthermore, there is a need for a theoretical framework that allows learning from different contexts, such as architecture, engineering design and product development in manufacturing. These factors contribute to the difficulty of implementing CE concepts in construction.

Section 4 presents the main results from an exploratory case study based on the implementation of planning techniques, originally developed for physical production, in the product development process.

4. EXPLORATORY CASE STUDY

4.1. OVERVIEW

The research strategy adopted in this exploratory study was action research, which is a strategy for obtaining both knowledge and change in social systems. It is a cyclic process, involving diagnosis of the problem, planning, action, and an assessment of the results. In this approach, the main focus of the investigation is the result of an intervention in the subject being studied (Eden and Huxham, 1997).

The exploratory case study involved the implementation of a model for managing the PDP and a planning and control system. The suitability of “the Last Planner System of Production Control”, proposed by Ballard and Howell (1994) for the preliminary stages of the PDP was tested. A small sized construction firm and an architectural design office were directly involved in this study. The construction firm main business activity is to develop and construct office buildings, and residential units for the middle and lower-middle class. Most of the construction work is sub-contracted, and typically one to three projects are launched every year. All the construction projects developed by this company typically start when a development opportunity is identified: the company buys a piece of land and hires external designers to develop the design. In general, sales start only close to or after the beginning of production stage, when the design is relatively advanced.

In this study, planning was defined as the process of setting goals and establishing the procedures to attain them, being only effective if intertwined with the process of controlling activity execution. Based on the model of production planning and control proposed by Laufer and Tucker (1987), two different control cycles were defined, one related to production control, and the other related to the preparation and evaluation of the planning and control process. Also, the proposed planning and control system was divided into three hierarchical levels (see figure 1): (a) long term planning, (b) look-ahead planning, and (c) operational planning, similarly to what is usually adopted for site production planning and control.

Based on the "Last Planner System of Production Control", a number of procedures and tools were developed to detail design activities, identify constraints, check constraints satisfaction, release work packages and allocate resources.

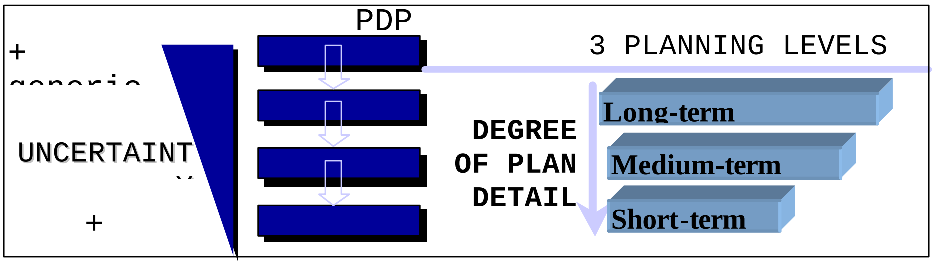

Figure 1: Product development process planning

A product development model, devised in a previous research project carried out at NORIE/UFRGS[5] was used as a starting point for long term planning. The model consists of a template that can be used by a construction company as a basis for designing the PDP for individual projects. The main elements of the model are: (a) the content of the main PDP activities, (b) their precedence relationships, (c) their main inputs and outputs, (d) tools for supporting the execution of such activities, (e) the role and responsibilities of the different actors, and (f) a model of the information flow. The construction and implementation of this model is presented in more detail elsewhere (Formoso et al. 1998, Tzortzopoulos & Formoso 1999).

The way the design process is divided into stages varies considerably in different studies both in terms of content and the names given to each stage (Cross, 1994). In this research, the PDP is divided into seven stages: (a) Inception and Feasibility, (b) Outline Design, (c) Scheme Design, (d) Design for Legal Requirements, (e) Detail Design, (f) Production Monitoring, and (g) Feedback from operation. Although there is a certain degree of concurrency in the proposed product development model, its approach is more similar to what Yazdani and Holmes (1999) named as design centred models.

The case study was focused on the development of one specific project, which consisted of a residential condominium for lower-medium class. The main strategic objectives of the project were: (a) low cost, since there was a fixed selling price; (b) good aesthetics; (c) functionality; (d) low maintenance cost. The case study started in April 2000 and finished in September 2000, being conducted during the three initial stages of the process.

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[5] NORIE/UFRGS is the Building Innovation Research Group from the Federal University of Rio Grande do Sul, Brazil.

4.2. CASE STUDY DESIGN

The exploratory case study was divided into three main stages: (a) preparation, (b) implementation, and (c) evaluation and guidelines for future research. The first stage aimed to obtain the commitment of all the parties involved in the work to be performed. It was agreed that the planning model would be implemented gradually, so that the product development team learn its features step by step. Short-term planning was initially focus for implementation, since it emphasizes the commitment of the teams involved with the goals established in routine meetings.

A short training on the basic features of the planning system was provided to the product development team. This was carried out separately for the construction company personnel and for the architectural design office, because it was the first time these companies were working together and thus the architects were not aware of the previously developed product development model.

Based on the PDP model, a number of improvements were included in the process, such as: (a) involvement of all designers and representatives of the production team in the early stages of the process (i.e. outline design); (b) implementation of work procedures, reducing the variability of some product development activities that are predictable; (c) establishment of process milestones, although there were some overlapping between stages; (d) introduction of data collection activities, which tend to improve the PDP performance increasing the availability of information to perform design tasks; (e) introduction of formal project reviews, as major quality control checkpoints, concerned with a range of issues, similar to the stage gate reviews proposed by Cooper (1988); and (f) introduction of formal technical reviews related to the integration of sub-systems.

The first deliverable of the case study was a long-term or master plan. An initial version of this plan was developed based on the activities prescribed by the PDP model and also on the strategic milestones of the project, such as date for initiating the legal approval and the beginning of the construction phase. Some adaptation of the sequencing of the design activities prescribed on the original process model was necessary, in order to adequate the model to the context of the project being planned. Due to the high uncertainty involved in the initial phases of PDP, and also due to the lack of information available, at that moment it was only possible to reorder and adapt the activities of the first stage of the project (inception and feasibility). Part of a long-term plan generated with MSProject software is presented as an example in figure 2.

After the development and approval of the long-term plan, planning and control started to be undertaken within weekly design meetings. Initially, the intention was to have meetings involving the design manager (representative of the construction firm), the director of the architectural design office and the two architects that were directly developing the design. Unfortunately the director of the design office could not take part in all design meetings, and this fact resulted in lack of commitment in relation to the plans produced during the design meetings.

At the end of the first stage of the process (inception and feasibility), the master plan had to be reviewed, since this stage took more time than initially predicted, and also because it was necessary to reorder and detail some of the activities initially planned for the second stage of the process (outline design). The same procedure was adopted at the end of the second and third stages.

ID	Task Name	Duration
1	**1. Inception and feasibility**	**34 days**
2	Land data and documents gattering	5 days
3	Product definition	1 day
4	Potential building area estimate	14 days
5	Legal information gathering (city hall)	1 day
6	Lland surveying	5 days
7	Land transaction	30 days
8	**2. Outline design**	**14 days**
9	Brief for completeness	1 day
10	1st Technology Selection	1 day
11	Architectural design alternatives	5 days
12	Evaluation of design alternatives	1 day
13	Evaluation of economic-financial feasibility	1 day
14	Adjustment of outline design	5 days
15	Contractual arrangements with architect	1 day
16	**3. Scheme design**	**25 days**
17	Soil survey	6 days
18	2nd Technology selection	3 days

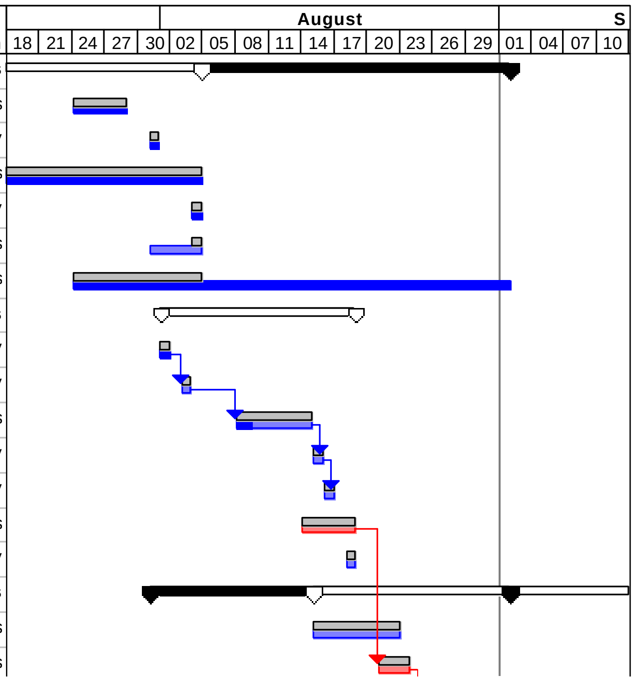

Fig. 2. Example of a long-term plan for product development activities

A number of tools were used in the case study for both data collection and implementation of planning and control. A form for short-term planning, similar to the one used in the “Last Planner System”, was devised. In the planning meeting this form was used to describe the work packages to be carried out, and to register the estimate their duration, their actual durations, and the causes of plan non-completions.

A product development process log, as presented in figure 3, was used to register every task performed daily either scheduled or not in the short term plan. Based on that, a map of the actual process was made, which was compared to the proposed plans. Such information was used to identify sources of deviations from the plans, providing an opportunity to learn systematically about the nature of the early stages of product development.

Project:	**Product development stage:**	**Initial date:**	**Documented by:**

Activity name **Action by** **Date completed**	**Main decisions made**	**Sub-goals**

Figure 3: The product development process log

Furthermore, a set of performance indicators related to the planning system was implemented. The main ones were: (a) Percent of Plans Complete-PPC (Ballard 2000); (b) PPC for each team; (c) delay projection; (d) percent of tasks started in the planned date; (e) percent of deliverables out of date.

The most important performance indicator implemented was the Percent Plan Completed (PPC), which is a measure of workflow reliability (Ballard, 2000). As stated by the same author, the improvement of workflow reliability is important for the productivity of linked production units and consequently for project cost and duration. Through the use of PPC it was possible to evaluate the quality of the short-term plans, identify causes of non-completion of plans and guide implementation of actions to improve the process. The PPC results are presented below.

4.3. PPC RESULTS

Figure 4 shows the PPC results achieved during the preliminary project stages. The evaluation was divided for the two different teams involved, architects and construction company. A gap was observed between the PPC results for each team in some of the periods. This fact explicitly shows that there was a high variability in the workflow within the process, and thus it was extremely difficult to implement control procedures. The high variability tends to increase the total duration and costs of the project.

It is important to note that during the weeks 4 and 5 there were no tasks planned for the architectural team. The architectural design had to stop due to the lack of definitions related to land purchase and also lack of information about legal aspects of the project. The construction company team underestimated the time necessary to release this information.

The lack of continuity of work tends to increase project costs, due to the extended project duration. It generates waiting times within the process, as well as waste related to the need to ~~of~~ rethink the work previously done each time the design restarts. Another important factor that contributed to high ~~increase~~ workflow variability was the fact that the design team was using formal planning techniques for the first time. Thus, there was no previous information available about the duration of activities.

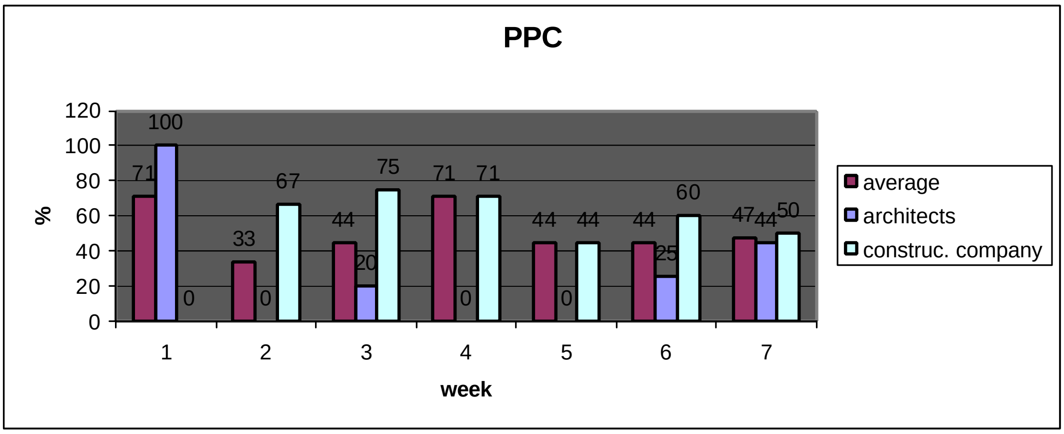

Figure 4: PPC results

The most important cause for the non-completion of plans was the lack of legal information, which should have been obtained from the local authorities. The second major cause was the “necessity to develop other work” that was not linked to this project. This was closely related to the fact that the director of the architectural office did not participate in all design meetings - he occasionally changed the architectural office internal weekly plan. Similarly to the study carried out by Koskela et al. (1997), the causes of plan non-completion are in general related to variability in the overall PDP or to the internal planning and management of each design discipline.

4.4. MAIN CONCLUSIONS OF THE EXPLORATORY CASE STUDY

One of the major benefits of using the PDP model as a basis for the long term planning of a specific project was the fact that it made simpler and easier the definition of activities. As the model provides a broad view of PDP, establishing the project milestones and process duration was relatively easy. Also, the formal stage reviews provided important reference for the long and medium-term planning. Both process transparency and predictability were improved in relation to previous projects, due to the formalization of schedules and also because of the use of performance measures, such as PPC, especially in terms of analyzing the impact of design changes and monitoring process progress.

Regarding the applicability of the PDP model, several changes in the content and sequencing of activities were necessary in order to adequate the model to the specific project being investigated. The main source of variability were the activities concerned with design itself – in fact, they had not been detailed in the PDP model, since much uncertainty and interaction exist between individual design tasks. These activities often influence the content and sequencing of non-design activities. Thus, a more flexible approach must be addressed to plan the PDP.

In this exploratory case study, it was not possible to fully implement the look-ahead (medium-term) planning. There is an inherent restriction on determining the most adequate design sequence in the early stages of a project, because this work content strongly depends on design decisions to be made (Koskela et al 1997). Such uncertainty makes it very difficult to define beforehand a detailed list of design work packages, including the required information for constraints analysis, necessary to enable the effective use of look-ahead plans.

Thus, the strategy adopted to link the weekly plan to the master plan was to detail the activities predicted in the master plan for the following stage of the process, at the end of the previous stage. Nevertheless, this strategy needs more investigation and also the development of supporting tools. Koskela et al (1997) also suggests that the chain from the master plan to the operational assignments is a research area for future development.

The use of the "Last Planner System" in the short-term planning and control was appropriate within the first stages of the PDP. The analysis of PPC results increased the transparency of the process, pointing out problems such as unnecessary stops in the process. Most participants of the project were surprised, when they became aware of the high variability in the process, expressed by that indicator. However, further adjustments of this tool to the characteristics of PDP seem to be necessary, aiming to increase the link between operational plans and the milestones established at a higher planning level. It is also necessary to gather more evidence~~s~~ on the ideal period of time for short-term planning in the initial stages of the project e.g. one or two weeks, depending on~~f~~ the design complexity, time pressures and degree of uncertainty involved.

Compared to physical production, the internal logic of the process has a much smaller influence on the way the PDP is scheduled. There are several factors that influence the order of design, such as controlling authorities, client interests, financial arrangements and order of site tasks. These factors must be considered, and usually they tend to increase uncertainty and negatively affect planning reliability. The case study indicated that systematic client requirement management can be introduced in the process through the use of the planning system, increasing the value of the product for the client. However, how this integration can be achieved is also an area that needs further research.

The effectiveness of the planning system depends directly on the commitment of each party involved. In this study, uncertainty related to the continuity of the project (due to land negotiation) and the lack of a formal contract between the construction company and the designers contributed to the lack of commitment of the parts involved. Differences between the strategic priorities of the design office and the construction company also contributed to this scenario.

The lack of commitment of the design office to planning led to unnecessary stops in the development of design. Other factors also caused delays in design, such as lack of information and the excessive time spent by the construction company to evaluate design alternatives. Besides, design analysis was carried out without sufficient market and client requirement information. Thus, a framework for supporting decision-making regarding the evaluation of design deliverables is also needed.

The planning system must be well understood by the actors involved. As a result of the insufficient training, some problems were also detected, such as planning tasks without input information available; errors in the definition of assignments; and misallocation of necessary time to perform a task.

Finally, all actors involved in this case study described that the implementation of the long and short-term planning and control system was beneficial for the PDP as a whole. They also pointed out the fact that a formal short-term plan to some extent~~d~~ improved the decision-making process.

5. FINAL COMMENTS

The need for improving the management of the PDP has been largely discussed in the literature. However, the managerial practices and techniques employed, especially in terms of planning and controlling this process, present little development.

The use of a PDP model as a basis for determining a long-term plan for a specific project seemed to be beneficial. Through its use it was possible to implement a number of improvements in the PDP. However, it was necessary to introduce changes in the content and sequence of activities to adequate the model to the project nature and context. The use of "the Last Planner System" proved to be suitable for the initial stages of the PDP, but further adjustments of the tool are still needed. The link between the master plan and the wee~~a~~kly plans is an important area in which further research is needed. Focus on process improvement can be achieved through the use of the indicator PPC.

The planning system can be used to support decision making throughout the process. However, new approaches to support design analysis as well as other decision-making support tools are necessary to ensure that the process develops effectively.

These factors indicate that new approaches to PDP management must be developed. Further research concerned with planning and control of product development must consider the differences in nature between design and production activities. In this respect, it is necessary to consider existing theories related to both product development and operations management.

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