PROPOSAL OF A SET-BASED CONCURRENT MODEL FOR THE CONSTRUCTION INDUSTRY

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ABSTRACT

Concurrent Engineering (CE) is commonly employed in high-tech industries. CE can generally be applied by means of point-based and set-based strategies. However, although several related studies have been published, these strategies still lack systematic structuring for the operationalization of CE in the Civil Construction Industry (CCI). The purpose of this study, therefore, was to develop a set-based operational model based on the Lean Project Delivery System (LPDS), since this system is designed for practices in CE environments. This is a theoretical work developed from the rationale that the use of set-based concurrent models can more adequately model the use of LPDS-based CE. The main contribution of this paper is the proposal of a concurrent model for managing the development of the design process in the CCI. This work is considered important for the sector because it expands the theoretical bases of the areas of construction management and economics by proposing an operational model that contributes to a better understanding and use of Lean philosophy in the design process in the CCI.

KEYWORDS:

Concurrent engineering, flow, collaboration, set-based strategy.

INTRODUCTION

Concurrent Engineering (CE) is concept well-known by companies that engage in large-scale manufacturing. From a conceptual standpoint, the characteristics of CE can be identified during the design phase because, unlike "sequential engineering," the activities in this phase involve practically all the factors that affect the product's behavior during its entire life cycle.

Vivan and Paliari (2012) believe that the concept of CE can be applied in various processes of a product, but its main focus is in the design process. Thus, CE can be understood as the integration of product design and production processes, i.e., parallel activities between the product and its manufacturing process, whose objectives are to reduce the product's development time and costs, and to better meet the expectations of the end user (Noble, 1993). In operational terms, CE-based models are developed using two different approaches: point-based and set-based. As will be demonstrated, the differences between these two approaches are easily explained from the perspective of information flow and how it can be related to the CCI.

In the brazilian Civil Construction Industry (CCI), the fundamental concepts and practices of CE are not easily identified or applied because, traditionally, the activities

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of the CCI in the country are based on sequential models of design management that do not value the exchange of ideas and information. Nonetheless, the academic community is engaged in a major effort to develop models for concurrent operations in the CCI, albeit these do not yet explicitly include point-based or set-based approaches.

The misconceptions about and lack of a model for the effective use of CE, not only by the CCI but also by other industries, often result in ineffective improvements based on these theories, which could be avoided by adapting these assumptions correctly to the context in which they will be used. In this regard, it should be noted that before these concepts are applied in practice in the CCI, their foundations must be fully understood and proposals should be developed based on the conditions in which they will be applied. In this context, Lillrank (1995) states that management innovations originating from a very different context from that in which they are to be applied must go through a process of transference that comprises the abstraction and adaptation of rationales or models.

Thus, this paper proposes to develop a set-based concurrent model starting with the systematization of the operational structure of LPDS order to satisfy the concepts of CE in the CCI. This model is based on the operational aspects of the conceptual framework of the Lean Project Delivery System (LPDS), since it is founded upon the principle of information exchange through interactions between teams and processes. The use of LPDS is considered feasible for the purposes of this article because it presents a well defined operating structure focused on the context of the CCI, facilitating the management of the main phases of the life cycle of a building, which includes the design process.

RESEARCH METHOD

The research method is divided into two parts. The first part involves the analysis of national and international research involving the concepts in question, thus providing the scientific framework for the objective of this article. The second part, which is obviously based on the first, concerns the development of the set-based model from the tenets of CE within the LPDS.

The model development was motivated by the following reasons: a)Lack of a theoretical model that demonstrates in an explicit and operational way, in the CCI, the possibility of organizing functional teams controlled by the set-based approach; b)In this sense, use the operating sequence of LPDS in line with the set-based approach.

The structure was based on the three principles of set-based CE proposed in the work of Ward et al. (1995), II Sobek et al. (1999) and Nahm and Ishikawa (2005), which will be demonstrated in the corresponding topic. The design of the model to be demonstrated, sought to use, then, the sequence of activities of LPDS associated with principles of set-based CE.

POINT-BASED AND SET-BASED CONCURRENT ENGINEERING

In sequential processes (as opposed to CE), the development of product engineering, and hence, process engineering, occurs through a series of functions, which are designed linearly and sequentially to come up with a single solution or detail. Thus, decisions and products resulting from the first phase generate the best solutions for the next phase, and so on. However, these solutions are based only on their own criteria, so that this manner of working is repeated throughout the remaining phases (Sobek II et al., 1999). In other words, the first phase of a project begins its activities by presenting a given solution, which is then introduced in the subsequent phases as quickly as possible. Thus, the remaining phases analyze the solution presented in the first phase based on their own perspectives.

In this regard, the authors claim that engineering inherent to sequential processes has shortcomings, mainly due to the delay or absence of information feedback. This is easily observed, for example, in the CCI, where the design process is highly complex, with numerous interdependencies, great uncertainties arising from decisions that are often imposed by customers themselves and by legislation, which are made under time pressure, since the disconnect between the various areas of the process is the leading cause of defects in the end product (Koskela et al., 1997). In this context, Song et al. (2009) claim that the traditional methods of project execution in the CCI are still grounded on practices that separate the design process from the production process.

Added value issues in projects are often restricted to architecture, so that clients internal to the process are ignored, precisely because there is no flow of information. For example, architectural design promotes a given aesthetic solution that pleases the end user of the building, but is unfavorable for intermediate actors such as production teams because there is no design for the production process of that solution, and hence, no added value for the production team (with respect to the design process). In view of these facts, Austin et al. (2007) consider that project design in the CCI portrays a given phase of the enterprise in which the complexity of this process is not well understood, and is therefore poorly managed. Moreover, in recent years, the CCI has become increasingly fragmented, largely due to the increased specialization of the professionals in this industry and to the increasing complexity of the methods and technologies involved (Austin et al., 2007).

In contrast, processes developed along the lines of CE allow for fast and efficient information feedback, usually through simple face-to-face meetings of multidisciplinary teams. With respect to research on concurrent engineering, there is a certain imprecision in terms of language, since different authors refer to this concept in various ways, e.g., strategy, tool, approach, or technique. In this paper, CE will be treated as a concept that shapes the operational practices of a product’s design process, since, as Gunasekaran and Love (1998) stated, CE is a design procedure that involves a series of phases whose characteristic activities are conducted in parallel rather than sequentially. This reduces the development time, giving the process significant advantages over the traditional methods. Thus, CE can be understood as an essentially design-focused concept characterized by a rigorous analysis of the initial requirements, which incorporates the constraints of subsequent phases by controlling the possible changes that may occur. For Koskela (1992), the main objectives of CE in the design process are reduced lead time, increased interactions between teams and processes, and fewer product changes.

The consideration of factors associated with a product’s life cycle during the design process may also characterize the presence of CE as a modeler of development and project management practices. In this regard, these factors can be identified as product functionality, production, assembly, testing, maintenance, safety, cost and quality. The essence of CE consists not only of the concurrency of activities, but also the cooperative efforts of all the teams involved, resulting in higher profitability and competitiveness (Abdalla, 1999). Tookey et al. (2005) argue that CE is based on the use of multidisciplinary teams to come up with design and production solutions as quickly as possible, allowing the product to be marketed in a relatively short time and thus increasing the company's profits.

Thus, it is reasonable to state that one of the main characteristics of CE is the synergy required between the processes (design and production), and hence, among the teams responsible for each task. Moreover, CE is identified in which a given number of tasks is developed in parallel, i.e., nonlinearly, by team members and leaders in different departments and locations, which means that all these professionals require simultaneous access to the same sources of information (Giudice et al., 2009; Antaki et al., 2010).

Sobek II et al. (1999) demonstrate that in companies such as Chrysler, key project team members get together once a week for an entire day; thus, changes required in the first phase are relatively easy and inexpensive, since the project team discusses a solution that will, in theory, satisfy all the subsequent phases. Within the context of CE, this approach is known as point-based, because it considers the interaction between phases and teams for the discussion of a single solution. For Ford and Sobek II (2005), in point-based approaches, project teams initially consider a range of alternatives arising from the perspective of each individual member, after which they rapidly select the most suitable alternative that best reduces design complexity and cost constraints. However, according to the essence of CE, the best alternative chosen by the project team, should be analyzed from multiple perspectives, with changes executed as agreed and the process of interaction continuing until all the constraints are satisfied (Ford; Sobek II, 2005).

The point-based approach starts with the generation of several alternatives that are rapidly evaluated based on the information available at the time in order to determine the best alternative (unlike the sequential model, which involves little or no interdisciplinary evaluation). The interactions between the teams in analyzing and refining the chosen alternative begin in only part of the company's entire organization, with the process continuing in other sectors in order to eliminate conflicts between its different functional areas (LIKER et al., 1996).

Problems with this approach emerge when the teams attempt to work simultaneously with different sets of information originating from different phases and areas (rather than with only one solution) (Sobek II et al., 1999). These authors demonstrate that once the design (and its solutions) has been examined by each of the teams responsible for a phase (different operational perspectives), each change proposed after the initial choice of a single alternative or solution will lead to rework and to additional requirements of communication between the parties, without any guarantee that the process will converge consistently toward an optimal solution.

Furthermore, Liker et al. (1996) argue that the changes that occur in subsequent iterations in point-based models can discredit the benefits of applying CE because they invalidate earlier decisions. Therefore, in this approach, much effort focuses on ensuring that the model will establish a good sequence between decisions so as to minimize changes. Thus, agreements regarding decisions to be made are crucial, forcing the participation of the teams in lengthy meetings and long review processes. Last but not least, this approach has been widely criticized for its inability to represent certain characteristics of engineering, the need for more extensive interactions, and the inadequacy of the models in exploring a broad set of solutions rather than a single ideal one (Finch, 1997; Chen; Yuan, 1999; Sobek II et al., 1999; Lu et al., 1999).

It should be pointed out that the difference between sequential and point-based CE engineering models is notable in that concurrent models consider constraints of subsequent phases based on the information flow from the other teams. Hence, even if the model's deficiencies interfere in the process, this already represents an improvement over sequential models, which do not include flows. Therefore, the differences in the facility of information flow of each model basically define their operational differences.

As explained, concurrent models structured by point-based strategies do not result in an optimal workflow (although they are a considerable improvement over sequential processes). Thus, it is feasible and necessary to cite the example of the Toyota Production System (TPS) strategy, whereby, unlike the point-based approach, CE is practiced based on a strategy of convergence of the alternatives (Ford; Sobek II, 2005). Sobek II et al. (1999) show that Toyota often uses a differentiated approach in the use of CE concepts to manage their products' design process, called the set-based approach. In general, the set-based approach was originally motivated by the nature of the effectiveness of the set of practices adopted in the vehicle development process of Japanese automakers (Sobek II et al., 1999; Liker et al., 1996; Ward et al., 1995). In TPS, the design team ponders about the product's development and offers a series of parallel and relatively independently solutions (not just one) to the other teams in charge of other processes (Sobek II et al., 1999).

Thus, it is valid to point out that the use of the set-based approach for concurrent models requires the absence of ambiguity in information and between such information and these professionals, and that the costs of implementing this type of strategy are low (Terwiesch et al., 2002). Ward et al. (1995), Sobek II et al. (1999) and Nahm and Ishikawa (2005) make an important point regarding the set-based strategy within CE, based on the elucidation of three principles which, according to these authors, comprise the essence of this strategy. These principles are described below, with a brief explanation of the considerations put forward by Nahm and Ishikawa (2005).

The first principle, called "Map the design space," entails multiple functions or teams that to define a broad set of solutions based on their respective areas of expertise. The second principle, "Integrate by intersection," considers that each team then gradually refines the set of solutions over time, eliminating ideas that are not considered viable from the point of view of the other teams. The third and final principle, "Establish feasibility before commitment," shows that each team continues the flow of communication regarding the considerations relating to the set solutions in order to obtain the set or sets of solutions, which are approved and accepted by all the teams.

Nahm and Ishikawa (2005) believe that set-based models are highly effective for the design and management of large enterprises. However, Nahm and Ishikawa (2006) point out that most research relating to set-based models is descriptive or prescriptive and does not provide details of methods to achieve the outlined principles. This is further aggravated in the context of the CCI. In Brazil, for example, CE is not a concept embedded in the management practices of companies, nor is there an understanding about point-based or set-based strategies. The application of CE in the CCI is still in a phase of understanding and development, according to several articles published on the theme, such as those by Gunasekaran and Love (1998), Anumba et al. (2002), Koskela (2007) and by Brazilian researchers such as Fabrício (2002), Vivan (2011) and Vivan and Paliari (2012).

Fabrício (2002) states that companies operating in the Brazilian CCI are unconsciously moving toward the implementation of integrated design practices. The author shows that the lack of a strategic plan for the introduction and development of new management models converges toward a partial and problematic implementation of CE by the CCI, because companies seek to combine traditional practices with the concepts of CE, creating conflicts and limitations in view of the potential for improvement of the new practices. The works of Vivan (2011) and Vivan and Paliari (2012) present a theoretical discussion of CE in the CCI in order to provide a foundation for the development of projects aimed at the production of prefabricated homes. However, the authors do not provide a model for the concurrent actions that designs such as Design for Assembly require. Therefore, a model for the use of the concepts of set-based CE is given below, based on the three above described principles, using the operational structure of the LPDS.

SET-BASED MODEL

Ballard (2000) sees the LPDS as a philosophy that encompasses a set of interdependent functions (ranging from the product's conception to its delivery and use), rules for decision-making, and procedures for the execution of processes, which enable and promote the use and implementation of tools such as BIM software in the appropriate moments and phases. The LPDS ranges from the initial definitions to the interaction between five phases of the enterprise, namely: project definition, lean design, lean supply, lean assembly and use. These five phases are comprised in two macro-phases called: Production Control and Work Structuring. The composition of the five macro-phases allows for an operational work structure that emphasizes information exchange between the teams responsible for each activity within the macro-phases of the LPDS. We believe that this is the main advantage of using Ballard's proposal (2000, 2008) for the arrangement of the set-based model for the CCI.

The initial rationale for linking the LPDS to the three principles of set-based CE is based on the following observation. For a given problem or proposal to be solved or developed considering the LPDS structure, the first information required is the input data, which enables one to begin developing the Work Structuring. This, in turn, will define how each team will operate based on the input data and according to the progress of the activities of each macro-phase.

Figure 1 illustrates the rationale of the set-based model and its development. This model begins by identifying a specific problem that can be solved during the design phase. Thus, according to the suggested structure, the identified problem reaches a General Coordination team. This team can be identified and composed of engineers with expertise in each LPDS phase, since this phase requires that the professional be knowledgeable and have a vision not only of design but also of the production and management of the inherent activities, as well as knowledge about the product in question.

Thus, after the General Coordination team has evaluated the problem, it divides the development tasks among the teams of each macro-phase by means of Work Structuring. Thus, each team is able to put forward proposals within its domain. The result of this Work Structuring will perforce be a series of proposals, suggestions, solutions and ideas that will be analyzed by the other teams of other the three macro-phases of the LPDS who will not participate directly in the work that led to these proposals. For example, the set of proposals resulting from the efforts of teams working within lean design will be analyzed by the teams working on project definition, in lean supply, lean assembly and use, so that the result of these analyses will be the one most suitable for all the phases. This can be construed as actions performed within the context of the first principle of set-based CE (Map the design space), as highlighted in the red frame in Figure 1.

During the process of analysis, these teams interact in face-to-face meetings (with small time intervals between meetings) or through electronic media (extranets, electronic mail or another system that meets the objective). After analyzing various proposals, the teams reach solutions that, in theory, meet the needs of each macro-phase. After this step, the General Coordination team selects the best results and produces a practical combination that should be developed (in order to be used). To this end, the General Coordination team produces a new Work Structuring so that the activities of the lean design teams are properly structured, and hence, developed. This comprises the second principle of set-based CE (Integrate by intersection), as highlighted in the blue frame in Figure 1.

The proposal that reaches the lean design team (i.e., the sub-steps of process design, design concepts and product design) is still not completely free from being rejected. The result of the first interactions with the General Coordination team may contain certain peculiarities, often due to abstractions that may not be compatible with a given activity in some phase of the LPDS. Therefore, the product generated by the lean design team is analyzed by the other teams of the macro-phases. If the final proposal is rejected by any of the teams, the process starts over with a new interaction. This consists of the third principle of set-based CE (Establish feasibility before commitment), as highlighted in the magenta frame in Figure 1.

Obviously, any proposed structure depicted in Figure 1 only works in environments that are aware that an information flow must be in place during the development of the proposals and must involve all the teams that represent the processes that precede and come after the project. Undoubtedly, it is easier to identify CE in companies that use work teams, and therefore it is relatively simple to manage the information flow.

This is not easy to observe or apply in the CCI, because the project teams (responsible for each area) and the teams working in other processes (production, sales, maintenance, etc.) work in different locations often separated by large physical distances that preclude frequent face-to-face meetings. To reverse this situation, this paper proposes the structure depicted in Figure 1. The scheme, modeled upon the concepts of CE, promotes interaction through the set-based approach (assuming a set of proposals is analyzed) among the main teams involved in the development and production of a building, according to the LPDS.

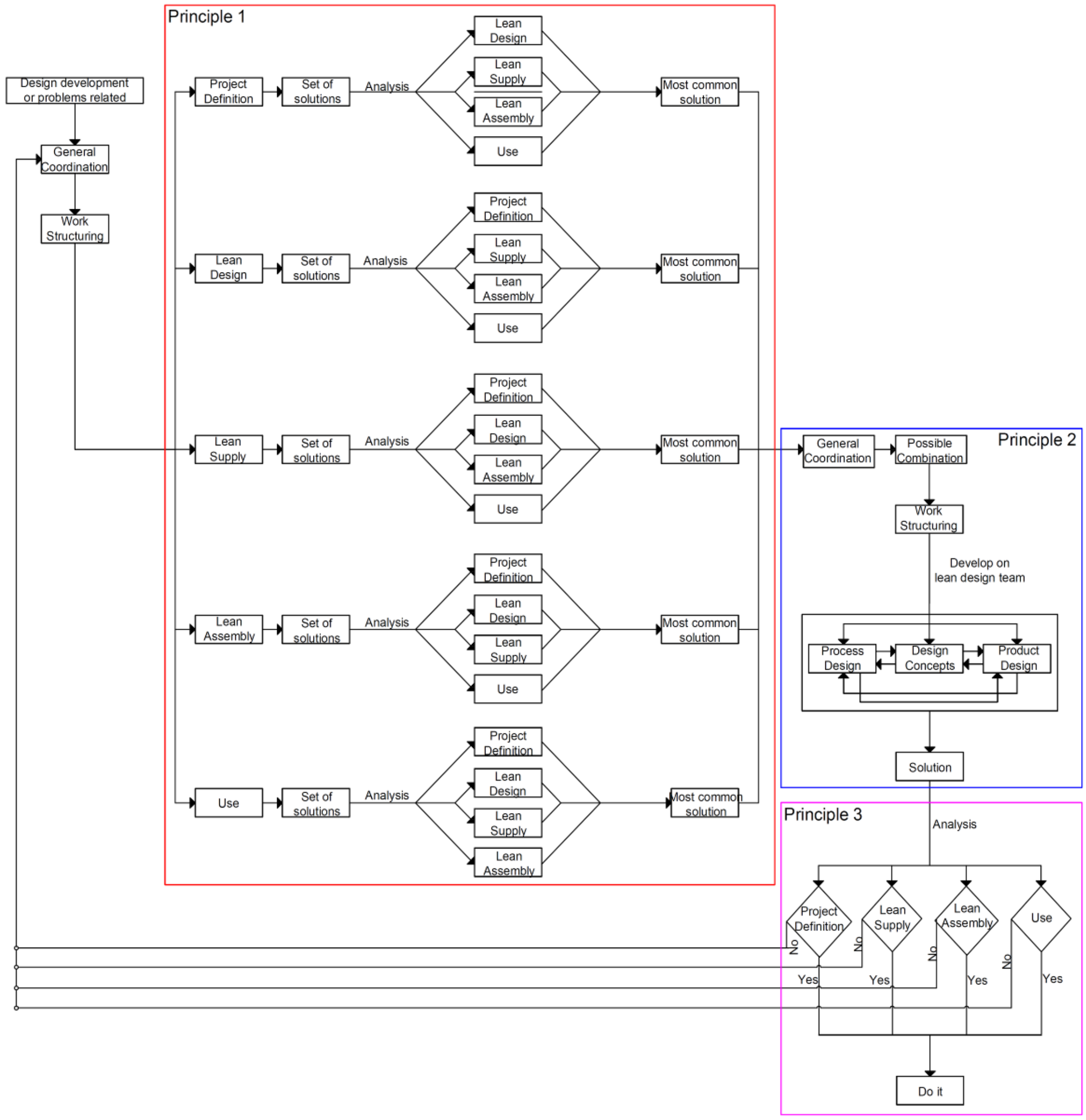

Figure 1: Set-based model

DISCUSSION

In modern industrial sectors, design is considered an essential phase of the enterprise and indispensable to production, and companies operating in these sectors adopt strategies based on concepts of integration between processes, such as CE. This enables the entire design process to be developed in a dynamic environment, where information is constantly processed, evaluated and used not only by one area of the project but by several simultaneously.

Basically, this means that before the design is completed and released for production, all the information has been coordinated to reduce or eliminate interferences between systems and subsystems that will form the product. Based on the ideal of modernizing the CCI, some companies and professionals envisage CE as a means, with a solid scientific base and proven success, whereby processes inherent to the enterprise can be integrated, tending to reduce product development cycle time and increase product quality at low costs. Thus, two strategies for the implementation of CE were discussed, i.e., point-based and set-based. The conclusion is that set-based models generate better results by facilitating information flow through more effective interactions among multidisciplinary teams. Moreover, the set-based strategy is closest to TPS practices. The information flow in the proposed model thus follows the three principles of set-based strategy, enabling greater interaction among teams, and hence, better results.

It should be noted that for the CCI, in theory, the proposals of this work are easier to apply and should produce better results for prefabricated construction systems, in view of their productive and managerial advantages for assembly activities in production systems. The use of CE in the CCI is a considerable challenge for the sector, in view of the working culture characteristic of this industry. The proposal of a concurrent model is aimed at modernizing process management based on the principles of Lean Construction, and at fomenting discussions about the themes addressed here to promote a better understanding of the conceptual relations in the construction industry.

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