INTEGRATED PRODUCT DEVELOPMENT IN BUILDING CONSTRUCTION: CASE STUDIES IN BRAZILIAN BUILDING COMPANIES

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Abstract
This paper presents a literature review about concurrent engineering and proposes a new model to analyse building design process. Concurrent engineering in the real estate and building construction sector is treated as an early bi-directional integration of three development process interfaces in the building project. A theoretical, concurrent engineering oriented model has been developed and put against descriptive case studies in three of the greatest Brazilian companies of real estate and building construction. As conclusions, a diagnosis of the integrated product development in those studied companies and some guidelines to improve the integration and the management effectiveness in the building design process are presented.

Keywords: Concurrent engineering, design management, multidisciplinary teams.

INTRODUCTION
In the face of the increasing demands in relation to products and processes, companies have been searching for new methods to develop their products and services, looking for quicker responses to the market changes and the new demands from society. Several companies from industrial sectors that employ state-of-the-art technology have been developing their products in a more integrated and collaborative way, by means of design methodologies characterized by the integration of the players involved in marketing, design and production of new products, according to the concurrent engineering approach.

The more classic definition to Concurrent Engineering (CE) is "...a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developer, from the outset, to consider all elements of the product lifecycle from concept through disposal, including quality control, cost, scheduling and user requirements." (Institute for Defense Analyses – IDA, 1988) apud (SPCD, 2002). And, the fundaments of CE, according to several authors, as Hartley (1992), Love and Gunasekaran (1997) among others, are:

- Multidisciplinary team participants interaction, emphasizing design coordination role;
- Product and production designs integrated development;
- Design integration of production process different players approaches. This is expected to occur by multidisciplinary team implementation that considers, while elaborating the design, the product life cycle;
- Strong customer and user satisfaction orientation (transformation of customers desires into design specification), eliminating activities that do not add value to the product.

Table 1 presents a brief summary of the concept and evolution of the concurrent engineering definition as proposed by many authors.

Table 1 - Characteristics and concepts of concurrent engineering

<table>
<tr><td>AUTHOR</td><td colspan="4">ELEMENTS CONSIDERED IN THE CONCEPT OF CONCURRENT ENGINEERING</td></tr>
<tr><td>McHugh; Wilson (1989) apud Junqueira (1994)</td><td colspan="4">Focus on the needs of internal and external clients;
Designing according to DFM process and organization aiming at parallel activities.</td></tr>
<tr><td>Chamberlain (1991) apud Junqueira (1994)</td><td colspan="4">Defining project goals;
Teamwork;
Parallel developing of activities;
Design standardization and design management process.</td></tr>
<tr><td>Carter; Baker (1992)</td><td>Organization;
Team integration;
Training and Education;
Support Automation</td><td>Communication Infrastructure;
Product management;
Product data availability;
Feedback</td><td>Requirements and needs definition;
Methodology planning;
Prospective planning;
Validation;
Standardization</td><td>Product development;
Value engineering;
Optimisation</td></tr>
<tr><td>Schrage (1993) apud Huovila et al. (1994)</td><td colspan="4">High-level approach to the project, based on engineering systems;
Strong client interface;
Multifunctional and multidisciplinary teams;
Project benchmarking and digital model prototyping;
Simulation of product performance and support and manufacture processes;
Simulation and evaluation of major predictable risks;
Early involvement of subcontractors and salesmen;
Company focusing on the continuous learning and improvement.</td></tr>
<tr><td>Murmann (1994) apud Huovila et al. (1994)</td><td colspan="4">Clear definition of the project objective;
Resources concentration in the beginning of the project;
Predevelopment aiming at reducing technical uncertainties;
Improving project planning;
Superposition of the development of parallel tasks;
Increase of the project administrator’s competence and responsibility;
Developing specialized and multifunctional knowledge;
Early consideration of the feasibility of the design concept;
Promoting the communication among employees;
Intensification of time control and development cost.</td></tr>
<tr><td>Hartley (1992)</td><td colspan="4">Multidisciplinary design teams;
Product definitions focusing on the consumers;
Product and manufacturing process simultaneous development;
Marketing and quality control.</td></tr>
</table>

According to Love and Gunasekaran (1997) CE application into construction products development may mean an important strategy to solve several deficiencies during project life cycle. Table 2 presents several construction problems that may be CE approached.

Table 2 - Improving construction efficiency by concurrent engineering strategy (Love and Gunasekaran 1997).

	Construction Issues	Concurrent Engineering Strategy
Quality	Clients' and end user Requirements	Systematic consideration of clients and end user requirements
Information flow	Interaction between participants	Team-building, proactive management, collaborative decision making
Efficiency	In-depth constructability analysis	Focus on the design and development phase
Project completion time and cost	Subcontractors, major subcontractors, rework and errors, inflexible procurement systems	Quality design and documentation, involvement of subcontractors and major contractors during the early stage of the design phase, CIM, robots.
Major cultural, behavioral, organizational, behavioral issues	Clients' and end user participants for co-operative supported work	Leadership, motivation, incentives, training, multimedia
Design optimization	Non-value adding actives, delay in the project completion	Design for constructability, design for quality
Elimination of non-value adding activities	Physical movement of resources, information exchange and hand over between subcontractors	JIT, life cycle design for construction, activity-based analysis

Despite its potential, construction CE application should be approached considering the sector characteristics that present several differences (partially listed on Table 3) from the industry as whole. Therefore, in order to implement construction CE practices it is necessary to define models and methods that may answer specific sector problems (Tahon 1997). Deep transformations, that include (i) firms and project organization, (ii) participants culture, (iii) new technology that support information and project must be introduced.

Table 3 - Construction peculiarities that may interfere on CE application (FABRICIO; MELHADO; BAÍA, 1999)

Construction project Nature	Project planning and programming, conception and design and production are much more spread in construction.
Culture and related Aspects	Players inter-relationship are much more temporary and contractual, not repetitive project cycle oriented; Differently from manufacture, as a whole, the clients generally interfere significantly on project internal management.
Suppliers	For several market and geographic reasons, same supplies maintenance, to different projects, is very difficulty; Considering firms involved different sizes, the negotiation power, concerning to suppliers is more limited.
Production scale	Construction usually works with small scales. This relatively decreases the product cost amortization possibility.
Construction site limitations	The production place (site) is more vulnerable to variations and climate phenomena in construction.

AIMS AND METHODS

The object of the present article is to translate and adapt the concurrent engineering concepts to the Brazilian building construction industry reality, together with the building real estate and construction sector, by means of operational guidelines that are adequate for this sector's reality. This paper focuses on the integration and collaboration of several existing interfaces among the players involved and through the development phases of building projects. This article has evolved from a literature review on concurrent engineering and from descriptive case studies of two large Brazilian real estate and building construction companies. A model is presented to analyse the product development interfaces in real estate and building construction companies in the face of the references provided by concurrent engineering methodology (item 3), critically analysing the product development process in the two studied companies (items 4 and 5) and directions and the necessity to implement concurrent engineering in building construction and real estate companies (item 6) are pointed out, from an analytical extrapolation of the case studies results.

PRODUCT DEVELOPMENT INTERFACES IN BUILDING CONSTRUCTION

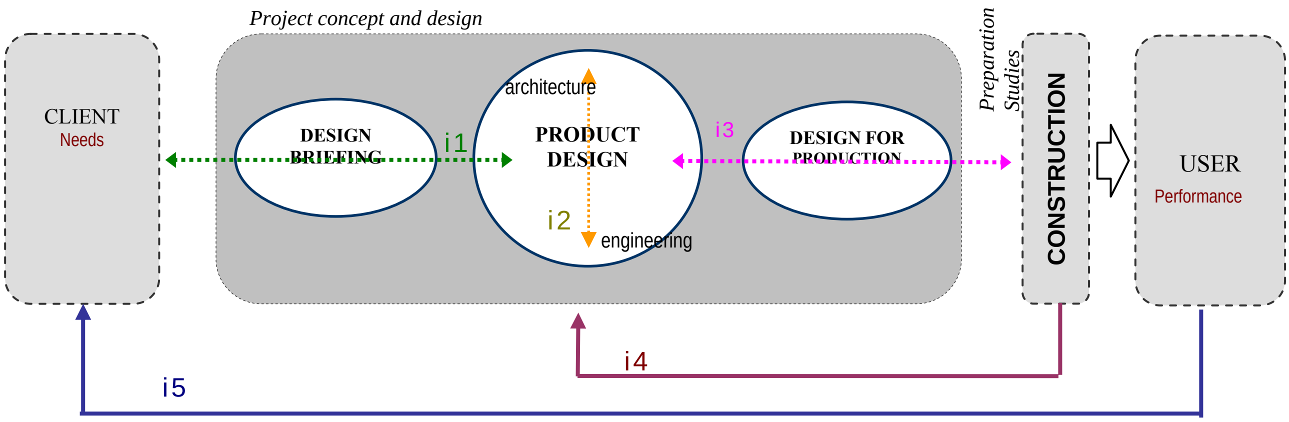
Throughout the development of a new building project several formulations, designs and plans are developed involving different players, making it possible to identify a series of interfaces between these stages and players. Due to the number of players involved in the design process, an organization of the information flow and competent management of the design interfaces deem necessary (Oliveira, 1999). In the sequential process of the product development the interfaces occur mainly in an unidirectional way, that is, after the formulation or conception of an aspect of the project design the generated information is passed on and such information is the starting point for the next stage.

The first interface (i1) lies between the market (demand) and the developer, and it can be named as client interface. This interface concerns the intermediation between the clients' needs and economic conditions and the development of a design. The interface between the speciality designers (i2) is a classical one and is related to the coordination of the designers' performance and the development of different design disciplines.

The i3 interface is related to the feasibility of the designs and to the development of the design for production, which can solve the constructive methods of the subsystems in the site work according to the product specifications. Interface i4 represents the need to follow up the construction and prepare the "as built" so as to guarantee the feedback of future designs and the maintenance of the constructed building.

Interface i5 is related to the project follow up during its use and maintenance phase so as to measure the accomplished results and the clients' satisfaction, by means of performance and post-occupation evaluations which investigate the performance from a technical point of view as well as from the perspective of the end users. The results of the evaluations should foster the development process of new projects thus creating a learning dynamics and the perfection of future projects.

Jouini (1999) and Melhado (1999) have identified three main interfaces in which *cooperation* and *integration* practices can be established. These interfaces are represented in figure 1 as (i1, i2 and i3) together with feedback on the execution (i4 – building interface) and usage (i5 –performance of the product being used by the client interface) phases. Figure 1 also makes a reference to ISO 9001:2000 with the process beginning with a client from the point of view of their needs and ending at the end user client with the performance of the product or service.



i1: market interface (design briefing);
i2: interface between product design specialties;
i3: product design – production interface (design for production);
i4: construction to design feedback;
i5: client interface (performance feedback).

Potentially simultaneous interface
Feedback interface (unidirectional)

Figure 1. Main interfaces in the design process (Fabricio, 2002)

Based on this product development interface model two case studies in real estate and building construction companies. This kind of company carries out private projects, involving both the project development (financial scheme set up and real estate business) and the building and construction management.

CHARACTERIZATION OF STUDIED COMPANIES AND THEIR PRODUCT DEVELOPMENT STRATEGIES

Case "A"

Case **"A"** is a private real estate and building construction company of national capital that was founded in the state of Minas Gerais in 1969. Nowadays it is considered to be a large company with circa 2500 employees, acting in the Minas Gerais state and the Distrito Federal, and in the State of Sao Paulo for eight years.

This company is aimed at high-income housing developments (high and medium standard apartments) as well as in the construction of commercial buildings (offices, stores, flats and shopping centres). The company has constructed over 200 buildings, 66% of which are high standard residential buildings, 14% medium-standard residential buildings and 20% commercial buildings. The company also has a QMS certified against ISO 9001 standard.

In company **“A”**, the selection of the sites to be acquired or exchanged is guided by its location and the opportunity to incorporate good areas, in privileged neighbourhoods in each city. The process of designing new buildings starts with the feasibility and concept analysis of a new project, leading to the product design phase, in which the design for production is also developed. The development of the business and the new projects briefing follows the classical strategy from the possibility of initiating a new project and a finance and economic feasibility analysis that will support the new project. As the company acts in market sectors with high standard of living (high income class), the definition of the project briefing is made in a more personalized way, according to the demands of this specific market.

In order to define the briefing of each building the following professionals are summoned: a real estate team (marketing and project analysis, financial analysis and land analysis), the company’s technical team (technical superintendent, design coordinator, site management team), and the architect. The engineering designers are contracted at a later phase of the design development. The company also creates design for production patterns of a series of subsystems of the building (e.g. windows and doors, façade covering, masonry, formwork design, etc), according to the list presented in Table 4. Such designs are subcontracted and developed concomitantly with the product design, to the exception of the formwork design, which is made *a posteriori*.

Table 4 – Design for production specialities – case study: Company A (Fabricio, 2002)

	DESIGN GROUPS	DESIGN SPECIALITIES / SUBJECTS
Design for Production	-	Concrete structure formwork; Partitions; facades; windows, doors and frames; Rationalized slabs; reinforcement; ceramic tiles; mortar; Waterproofing; etc.
Consultancy	-	Cost; Budget; Buildability improvement; Critical analysis of structural design; Critical analysis of HVAC design; etc.

Contracting the designers takes into account previous experiences, assessing the designers’ qualifications according to the QMS of the company, and, as a last criterion, reference from other clients.

An architect from the building company is responsible for coordinating the design, and such professional is in charge of conducting all the design process as well as validate the solutions proposed by the subcontracted designers. The design validation and the compatibility among specialties is extremely valued in the company and the design coordinator is responsible for checking the designs with the help of an extensive checklist. The coordinator must also superpose the several designs and verify the compatibility among them. This analysis is carried out by a matrix analysis system, which forces the coordinator to give an opinion about the compatibility of the designs in each quadrant of the matrix.

Case “B”

Company **“B”** is a major real estate and building construction company specialized in housing, acting in the middle class sector in several cities in the country, but its main market is in the city of Sao Paulo. Nowadays this company has a quality management system for its process of real estate development and construction of residential buildings – certified against ISO 9001 standard.

The competitive strategy of this company focuses on the search for cost reduction and the improvement of sales conditions of their buildings so as to make it possible for middle class consumers to buy apartments straight from them (Fabricio, et al. 1999). In order to make this strategy viable, the company has designed a self-financing scheme of their projects in which a considerable part of their construction cost is financed by the clients themselves and by prolonging the time for payment.

Prolonging the time for payment influences a series of briefing and design decisions. Thus, the choice of fast construction alternatives is not of great importance, once the duration of the project is not determined by technical limitations, but by the financial capacity of the clients. This favours the technological alternatives that present lower execution costs, regardless the required construction time.

In this context, the adoption of industrialized and prefabricated constructive techniques is not stimulated, favouring the rationalized traditional construction processes, which are more adequate to the "project duration *versus* payment flow" balance. In fact, this seems to be the strategy adopted by the company to allow a better result of their projects cash flow. While the structure and vertical sealing are designed with traditional technologies (*in site* formwork concrete or structural masonry) the installation and finishing projects are designed to be executed fast, near to the project delivery date. This way, many of the adopted design solutions such as ready shafts, windows and doors, exemplify the existence of designs focused on a greater rationalization of the solutions from a technical point of view, associated with the viability of the adequate cash flow. By allowing a slow execution of the project at the same time delaying expenses with important sub-steps of the construction process (installations, finishing, etc), the company meets the clients' wish to see the project advance, besides assuring a better cash flow for the project (Assumpção, 1996).

To complement this cost reduction strategy from the production point of view, the company has been making an effort to standardize and simplify their buildings, reducing the costs by eliminating expensive design details and by large scale gains with the large series of projects, which allow the maintenance of a relatively constant number of construction sites, thus reducing the final cost of the projects and guaranteeing a relatively constant volume of demand input.

Following the standardization strategy, the design briefing of each project derives from a pre-established basic briefing, developed by regional product and marketing directors. In order to prepare the basic briefing, the market experience of each regional branch of the company is taken into account and qualitative surveys are carried out with the potential consumers. With this information, meta-briefings are developed for each region where the company acts in, so as to ponder on the regional idiosyncrasies (larger balconies in Rio de Janeiro and seaside cities in general, balconies with a barbecue grill in Porto Alegre, badminton courts in Minas Gerais, etc).

From the typological definitions (basic briefings) of products that meet the needs of a selected market niche, the company develops a series of standards and procedures for concept and design, which serve as guidelines for the design development. The selection of the site, one of the first decisions in the concept of the project, is subordinate to the search of sites that adequate to the kind of product and the clients niche the company wishes to reach. From that, the design briefing follows the pre-established patterns of the company.

The simplification and standardization achieved by the company make it easier the development of partnership with suppliers, once they allow the company to work with a reduced number of well-known brands and types of materials, components and services, taking advantage of their large scale production to negotiate better prices of these items. The preoccupation in designing the production is, according to the company, incorporated to the product executive design and the production standards and procedures in its QMS and, specifically in masonry, to contract a design for production specialist.

With regard to the relationship of the company with the other project players, it is possible to identify two main types of partnership with distinct reach, involving materials, components and design service suppliers and subcontractors. Not only is this distinction between partnerships due to the nature of the given input – product or services – but also to the power of negotiation with suppliers and to the objectives of the company for each kind of input.

As to materials and components, the company concentrates on the establishment of partnerships with well-known suppliers on the market in order to obtain better buying conditions and, in some cases, as a marketing strategy, guaranteeing to their clients that their apartments will be built with materials from respected brands.

The strategy for service suppliers and subcontractors is far more comprehensive and ambitious. In the case of partnerships with designers, the company has developed a series of patterns and standards of design presentation aimed at certain standardized criteria and solutions, so as to simplify the plans and guarantee a better construction besides making design more transparent, manageable and adequate to the site work environment.

When contracting designers, partnerships with professionals already familiar with the company's practices and design standards are taken into considerations, besides following the qualification criteria and suppliers evaluation of the QMS of the company. The company also demands that meetings are arranged with the designers so as to coordinate the design along its development. The meetings schedule as well as the partial and final design presentation deadlines and the information exchange moments among the designers are defined at a first meeting.

The company adopts a similar policy with the subcontractors. They are expected to follow a series of construction procedures and meet the deadlines established by the company. In order to guarantee the fulfilment of the procedures and deadlines, the company and the subcontractors carry out brief training sessions with the workforce at the beginning of each task considered important.

Therefore, we may highlight, according to Fabricio et al. (1999), those partnerships do not necessarily guarantee an equalitarian relationship among the involved parts. In the studied case, the construction company exercises its preponderant negotiation power with the designers and subcontractors, thus moulding partnerships according to their strategies and at their convenience.

THE PRODUCT DEVELOPMENT INTERFACES FOUND IN THE CASE STUDIES

In relation to **interface 1** (design briefing-detailed design) companies **A** and **B** start from the traditional references from the market, prizing the definitions consolidated on the development and sale of previous projects and, occasionally, from carrying out qualitative market surveys.

In company B, the briefing integration with other decision areas is strongly guided by a meta-briefing, established by internal standards and procedures that serve as reference to the designers. The design briefing in company **A** is made from case to case, which allows a more collaborative "i1" in relation to company **B**. However, an important limitation is the absence or the informal participation of the designers responsible for the product engineering and the design for production. As to **interface 2**, in all analysed cases initiatives with the intention of qualifying the coordination process of the design for production were noticed.

Company B has developed its own coordination process, establishing in a more precise way the designers' responsibilities and defining a series of products criteria to be followed (design standards and patterns), as well as a rigid code system and design presentation and the use of icons instead of the standard symbols to describe information such as light, telephone, etc more clearly, making the information in the design more transparent to the workforce in the construction site.

In both companies design coordination meetings used to be more numerous. However, with time it was noticed that one, two or three meetings at most, are enough to establish contact among designers and between these and the construction company, which shows greater maturity and objectivity in the organization of such meetings.

The use of electronic media (e-mail, Internet, Intranet, Extranet, etc.) has increased in both companies, as a communication tool and to exchange projects, reflecting a growing tendency of using nets to manage information in construction. In both companies the exchange of design files is organized in a way it is centralized in the construction company, i.e., the exchange among the designers are mediated by the design coordination department, which is responsible for the information control. In company **B**, the coherence between detailed design and briefing (i1) as well as the coordination of the product design (i2) are based *a priori* on the design standards and patterns and on the pre-established basic briefing. Therefore, the case-to-case collaboration in the design concept is replaced by the company's strategy premises, which underlie all the planning and briefing process of the project. Despite that, the company has been successful in developing products that meet their business strategies and satisfy their clients.

In both companies the engineering and specialties designers are hired after the architectural scheme design is developed, that is, when various concept decisions had already been made. This attitude brings a double problem to the collaboration among the designers: on the one hand, the existence of ready and consolidated architectural solutions makes it difficult and does not stimulate that suggestions are made on the part of other designers, who tend to conform to the given conditions; on the other hand, when important suggestions are made and accepted, the architectural design has to be remade. The product engineering specialties designs are developed simultaneously. However, even among these many design coordination and integration problems can be observed, such as the difficulty to find a compatibilization tool and the time spent on information exchange among others.

In the studied cases, only company **A** makes extensive and systematic use of designs for production. Company **B** justifies the absence of such practice with the incorporation of building execution specifications to the product design.

In fact, the simultaneous **interface 3** only is extensively developed in company **A**. In this case, the design for production is initiated before the product design is ready. Besides the subcontracted designers, the company invites the future site engineer of the building that is being designed to take part in "i3". This allows both the anticipation of how the building is going to be produced and the discussion about the feasibility of the product design.

In company **B** the development of a new design code system with colours and icons, aiming at a greater transparency of the design plans with the workforce, represents an interesting integration effort, even if limited, between the design and the site work (interface i3).

In company **A** concrete actions and preoccupations to aggregate their building experiences and their clients demands and complains to the concept and development of their briefing and detailed designs were observed, creating a **fourth interface – i4**.

This company has also introduced an automatic process of recording complaints and suggestions made by their buildings end-users, monthly systematized into Pareto diagrams, which support the concept of new projects. For example, based on the complaints on the noise made by the installations, the company has determined that the shafts cannot be designed next to the bed headboard, demonstrating the existence of feedback related to the **fifth interface – i5**.

CONCLUSION

Concurrent engineering applied to building construction must seek to guarantee a collective authorship in the building design process by coordinating the efforts of different design players and specialists from the beginning of the product concept and development process, aiming at integrated and global solutions.

The case studies have indicated a greater preoccupation on the part of the companies with the design process, especially with the design coordination (i2) and with the integration between design and construction phases by the growing introduction of design for production. (i3). In this sense, it is possible to identify that the building companies are seeking more integrated design practices. However, the absence of a strategic plan for introducing new management models causes what can be described as a partial and problem implementation of concurrent engineering, with the concomitant adoption of innovative procedures and traditional practices, what many times creates conflicts and limits the potential of improvement of the new practices.

Another lesson that can be learned from the studied cases is that there are many different practices to organize, manage and integrate the building design process, which demonstrates that it is possible to introduce new and more integrated management practices, and that the design process and the production process in the sector is not predestined to reproduce classical models and stages.

In the studied cases it was possible to identify positive points in the design coordination, especially related with the coordination efforts between specialty designs and between these and the building team. Still, there is not yet a treatment of all the interfaces combined. The efforts of modernization in the design management process in the studied cases, however promising the partial results may be, demonstrate the absence of models capable of globally treating the integration of the design process with the client function, with the construction processes and finally with the whole project life cycle. In order to attain the integrated development of the potentially simultaneous interfaces, according to the model presented, the three major development interfaces of a building must be treated as a whole.

On the one hand, it is necessary to make a deeper development of marketing techniques and the relationship of the promoting companies with the clients and users in the first interface (i1). On the other hand, it is fundamental to have a more dialectical relation between the design briefing and the design detailing decisions.

As interface (i2) is concerned, it is clear that the design coordination must be recognized as a fundamental activity in order to guarantee the coherence among the specialties solutions, and to do so, a coordinator must take upon the task of promoting information exchange and mediate the conflicts among the various designers.

For the interface between the design phase and the building (i3) it was discussed the use of design for production and integrate a deep reflection about the construction process in the design stage, so that the design decisions take into account the developments regarding the building and its construction.

The empirical evidences and the literature analysis have made it possible to confirm the hypothesis that the building design process can be qualified and optimised by introducing new management practices based on the premises of concurrent engineering. However, they must be adapted to the building construction conditions and to the particular needs and possibilities of the building projects.

The adoption of the concurrent engineering represents a significant advance in the way of focusing the product development in building construction, involving in the design process all the aspects of a project life cycle and it can allow to improve the performance of the design process, thus improving the building product quality.

With the perspective of formulating an analysis on the possibility of transformation of the design process management as guided by concurrent engineering, multiple implications and potentialities related with the theme have been investigated. This way, countless questions were raised, but definitive or thorough answers were not given. In fact, these topics are part of a mosaic of subjects approached in a PhD research (Fabricio, 2002), which indicates that additional studies can be made in order to clarify the raised problems and tendencies.

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