Chapter Six

Concurrent Design: A Model for Integrated Product Development

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Introduction

Conventionally, the development of a building project is clearly divided into stages. In this divided and sequential process the possibility for collaboration between the various participants is rarely ideal and often fragmented. Changes to the design easily could result in significant rework and errors due to the complexity of coordinating and checking multi-authored information. Furthermore, participation of contractors, subcontractors, material suppliers and users in the design phase is sometimes very limited, which can lead to a gap between the product design definitions and the production design definitions. In an attempt to overcome these shortcomings inherent to a sequential process, concurrent and integrated working methods have been developed and implemented, aided by rapid developments in information and communication technologies. In concurrent engineering models the coordination of work packages can help to foster integration, multidisciplinary interaction and decision-making. Concurrent design, as argued in this chapter, takes the concurrent engineering philosophy and applies it specifically to the design of buildings.

This chapter presents two case studies that characterising contemporary practices for developing new building projects in São Paulo City, Brazil. The case studies analyse two building construction and real estate companies as to their product development process, mainly considering the integration between new product development and production and competition strategies. The case studies were developed based on an analytical model in which five product development

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interfaces were proposed. Also considered was the alignment between the company's product development process (PDP), its competitive strategy and its production strategy.

Concurrent building design

Integrated product development is supported by different approaches that emerged and were practised in the late 1980s and the 1990s, the most well known being concurrent engineering. Concurrent engineering (CE) emphasises parallelism and multidisciplinary collaboration in the product development process and particularly emphasises the need to integrate new product development (product design) with the development of production design technologies (Paashuis, 1998). Initially, concurrent engineering focused on technical and engineering processes; then the development process view expanded to incorporate pre-design activities, linked to marketing and market prospects, aligning the product development process to the corporation's strategic planning. Over time concurrent engineering has developed to include product follow-up, which helps to obtain knowledge and learning that can be configured into a management approach for the entire product life cycle.

Product development process (PDP) is an approach used by the manufacturing sector that comprises the product design and its production process. This is more comprehensive than the traditional methods adopted by construction companies, who mostly focus on the product production process. PDP involves the formulation of needs, design and development of the product's formal, functional and technical characteristics, but also design and planning of the necessary production means, including follow-up on the product's performance in use. Progressively, the design process involves the participation of more design disciplines in specialised functions, motivated by the growing complexity of products and the need for design solutions of greater technological complexity. In this context, the management of new product development processes tends to be structured in a specialised, hierarchical, sequentially organised way (e.g. Womack *et al.*, 1990). With the dissemination of the lean production paradigm, the flow of activities and the concept of added value gained prominence in industrial production strategies. Design is increasingly seen as a priority phase for adding value to products (e.g. Koskela, 1992).

Concerning the direct transfer and application of concurrent engineering concepts, methods and techniques from other sectors to construction, one should consider, as pointed out by Jouini and Midler (1996), that management practices are not 'packages' that may simply be transferred from one industrial sector to another. Important differences exist between each industrial sector which have to be considered and which might result in the need for adjustments to the model for it to be relevant; otherwise it could result in rejection. Recognising the peculiarities of design and construction projects there is no reason why the new design paradigm based on cooperation, communication and the interactivity of multidisciplinary parties should not be valid for changing and improving the building design process (Tahon, 1997). A specific model for integrated design process management was developed, specifically oriented to the sectorial characteristics and possibilities of the Brazilian construction sector; capable of reflecting the current paradigms of design organisation and the new technological possibilities for dealing with and organising the information flows. The concurrent design method described below starts from the collaboration concepts and philosophies guiding the CE application in other industries, yet it does not seek to impose the strictness and the complexity of the methods and tools associated with CE.

An important question concerns the relevance of the term ‘concurrent engineering’, faced with the practices and characteristics of the construction sector. Indeed, the complexity of building projects that involve real estate, urban planning, technological, constructive, cultural and historical issues transcends the (constrained) scope of engineering and arguably makes the term concurrent engineering limited when faced with the set of professionals and problems involved in the architectural design process. For this reason, the term ‘concurrent design’ (Fabricio and Melhado, 1998) was used. Indeed, the concurrent design concept should be understood as an adaptation and transformation of concurrent engineering to the construction sector. Concurrent design seeks to converge, in the building development process, the interests of the different actors participating throughout the project life cycle. The philosophy considers the consequences of design decisions in the efficiency of the production system and in the quality of the buildings generated, involving aspects such as buildability, liability, maintainability and sustainability that are increasingly considered as competitive advantages in the construction market (Fabricio and Melhado, 2001).

According to this philosophy, organisation of the design process must consider the interaction of many designers and engineers involved in the process, both face to face and at a distance, so that the multidisciplinary design work develops concurrently and project decisions are taken in the light of shared knowledge. It would appear that some evolution is required in three areas in order to operationalise effective concurrent design of buildings (as illustrated in Figure 6.1) – player culture, design support technology and organisation of the

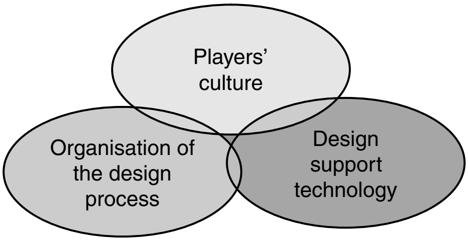

Figure 6.1 Areas for change to assist implementation of concurrent architectural design.

design process – as well as their interactions, represented by the overlapping areas in Figure 6.1.

The first evolution concerns transformation in the culture of the players involved, so as to overcome the constraints of the implied contractual structures and to create a new disposition for technical cooperation between design teams, contractors and developers. The second evolution concerns the application of new information and communication technologies facilitating virtual communication and allowing a new cognitive and technological environment for the design process. The third evolution comprises the organisation and coordination of design activities to allow parallel sub-product development by the different design disciplines. From these transformations, it is possible to establish a new base for treating the design process interfaces and for increasing interactivity and collaboration among the different players of the project, which directly or indirectly contribute to the creation and realisation of new products. From another viewpoint, one can say that the evolution has already happened in some construction projects and the model can help to identify better which are the best PDP practices.

A concurrent design reference model for analysing PDP integration

Fabricio (2002) proposed a concurrent design model to improve the degree of integration in the development of new construction projects. The model was also developed to serve as a reference for construction companies that want to improve articulation in the development of their products. It serves as an integration model for the development process of new building projects, aiming to support the practices developed by leading companies. The model has been used by a number of companies, as reflected in the two case studies described below.

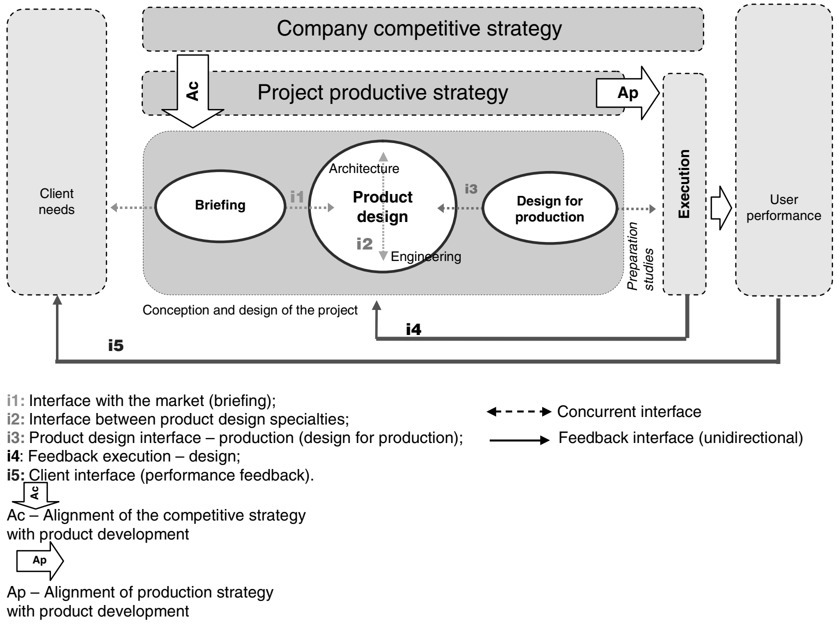

Figure 6.2 Major interfaces in the design process (adapted from Fabricio, 2002).

The model addresses the interfaces between the main phases of design and construction projects, as shown in Figure 6.2. The first interactive interface (i1) exists between the demand and the developer and may be called the interface with the client. This interface deals with the mediation between the client's needs and economic conditions and design development. The interface between the design disciplines (i2) is related to the coordination in the design team and in the collaborative development of different design disciplines. Interface i3 is related to the buildability of design solutions and the elaboration of design for production. Working concurrently with the product specifications helps to clarify work packages and sub-systems.

Interface i4 represents the follow-up need of the work, issuing from use of design as information for construction activities on site, and elaboration of the 'as built design' (record drawings) and all other actions of improvement in order to ensure feedback for future designs and the maintainability of the finished building. Interface i5 relates to the project follow-up during the use, operation and maintenance phases in order to assess performance and client satisfaction. This is achieved via post-occupancy evaluation, which investigates performance from a technical point of view and includes users' perceptions. The results should feed into the development processes of new projects in order to create a learning dynamic and (hopefully) better projects. Interface i5 should provide the product development process with information on the performance, pathologies, costs and building service life, so as to provide a life-cycle view.

Another area of analysis is the integration of the product development process with the competition and production strategies of the company, which marks the alignment of the product with the characteristics of the company actuation market and its competitive bases and with the production technology employed by the company (Ac and Ap – Figure 6.2).

i1: interface with the market (briefing);
i2: interface between product design specialties;
i3: product design interface – production (design for production);
i4: feedback execution – design;
i5: client interface (performance feedback).
Ac – alignment of the competitive strategy with product development
Ap – alignment of the production strategy with product development

The case studies

Brazil has the largest domestic construction market in Latin America. Located in the south east of the country, São Paulo is Brazil's most important city and is the third largest in the world, behind Tokyo and Mexico City. São Paulo is also the most significant Brazilian state for development. In the past decade globalisation, market openness, privatisation of state-owned enterprises, monetary stability, fiscal constraint, changes in the procurement law, decline in profit margins and increasing customer consciousness have collectively contributed towards the shaping of the Brazilian construction sector (Grilo *et al.*, 2007).

Two case studies that characterise contemporary practices for developing new products (building projects) in São Paulo City, Brazil, are described below. The case studies analyse two building construction and real estate companies as to their product development process, mainly considering the integration between new product development and production and their competition strategies. The case studies were developed based on the analytical model described above, in which five product development interfaces are proposed, being the three former (i1, i2 and i3) potentially concurrent or integrated and the two latter (i4 and i5) feedback interfaces. Also considered was the alignment between the company PDP and its competitive strategy (Ac) and production strategy (Ap). Nevertheless, in these two case studies only interfaces i1, i2 and i3 are described in depth.

In the first case study (Company A) the focus is on the interface between the commercialisation strategy and the product development process. In the second case study (Company B) the main focus of analysis is on the integration between the company product development process and the introduction of technological and productive innovations at the building construction worksites. In both cases, the product innovations were investigated and characterised, as well as to what extent these innovations were supported by innovative and more integrated PDP.

Case Study A

Company A is a large building contractor and real estate developer of residential projects, operating in markets connected to building construction and with regional offices in large Brazilian cities such São Paulo, Campinas, Porto Alegre and Rio de Janeiro. When the case study was conducted the company's main target market was the lower- middle class sector.

In this case, alignment was especially important (Ap and Ac in Figure 6.2). In building construction in Brazil, given the size and the high cost of the products (apartments, houses and real estate in general), the sales are highly dependent on long-term financing. This type of financing is generally made by banks and by public players fostering housing. However, in Brazil, the availability of real estate financing through the bank system, since the extinction of BNH (National Housing Bank) in 1986, tends to vary significantly, being particularly scarce during most of the 1990s and early 2000. To adapt to this scenario and allow the commercialisation of housing for a lower-middle class public, in 1992 the company developed an innovative long-term (100-month) self-financing strategy for their projects. In this financing system, a large share of the construction costs were financed by the clients themselves by means of a sales scheme similar to that of a consortium. Thus, a large project, composed of several similar residential high-rise towers, with different construction deadlines and delivery dates to the market is commercialised to clients. Products being equivalent, the clients receive their completed estate according to the amounts paid, resulting in a kind of bidding process, in which those who contributed a larger initial payment would get their estate earlier than those who paid less. Thus, the company projects were planned to be built over a long period, varying between 3 and 6 years.

To meet the goal of elongating the work deadlines and also reducing costs, the company product development plan had to be reconfigured to facilitate compatible design alternatives. The first parameter to be met in the new product development scheme was that project construction speed should be determined by the clients' disbursement capacity, valuing technological alternatives that allow for lower execution costs, independent of

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the execution time required. In this context the adoption of industrialised and pre-moulded techniques is not stimulated, favouring traditional (slower) construction processes, which allow more flexibility concerning the synchrony 'work speed versus payment speed'. This was the strategy adopted by the company to allow a better cash flow for its projects. Therefore, whereas the hard work (structures, sealing, etc.) was designed with traditional technologies (concrete moulded in situ or structural masonry), the fitting and finishing designs were oriented to allow fast execution, closer to the project delivery deadline. Thus, a number of design solutions adopted in the company projects, such as plumbing and electrical shafts, and ready-made doors and windows, exemplify the existence of designs focused on technical solution rationalisation, while aligned to the project cash flow.

From a design for production point of view, the company made great efforts to simplify and standardise its buildings, reducing expenses by eliminating costly design details and by the scale gains obtained with the maintenance of a very large and linked flow of work, allowing the maintenance of a relatively constant production output.

The project briefing derives from a pre-established basic briefing strategy, developed by the regional product and marketing boards. The elaboration of the basic client brief, despite retaining a strategy defined by the market niche and by commercialising the product by self financing, considered the experiences of each regional office of the company and previous experiences with apartment commercialisation in each locality. Qualitative surveys were conducted with prospective customers in a decentralised way by the local offices to help inform the briefing process. Standard briefs were developed for each region of the country in which the company acted, keeping the general long-term commercialisation guidelines and the focus on the lower-middle class niche, complemented by regional specifics. This meant that building products had to consider the local urban development dynamics (real estate values and opportunities for incorporating new plots), as well as idiosyncratic regional demands, such as larger balconies in Rio de Janeiro and other coastal areas, verandas with barbecue grids in the city of Porto Alegre, shuttlecock courts (a form of Brazilian badminton) in the Triângulo Mineiro region and so on.

Company A developed a bespoke design coordination process among the different designers (engineers and architects). This helped to more precisely assign each designer's responsibilities, the scope of each design package and definition of the different standardised product specifications to be followed. Interface i2 was then satisfactorily implemented.

The company also required the designers to hold design coordination meetings during the development period. Initially, the company tried to hold meetings on a regular basis. However, as the project dynamic matured the company gradually decreased the frequency of the coordination meetings and concentrated the meetings at key interfaces. These were held at the transition between each specific design phases, resulting in around three major meetings during the process. Exchange of design files among the different participants had to go through the company design coordination process, which had the mission of receiving, verifying and passing on the drawings and information to the other designers involved. At the time the study was conducted at the company, these exchanges predominantly occurred by regular e-mails.

Concerning interface i3, Company B took advantage of its standardised constructive solutions, and to communicate design information to the site workers the company implemented its own nomenclature, using colourful icons to better illustrate information such as light and telephone points, etc., instead of standard graphics. They also tried to provide easy-to-use drawings on the site, limiting the size of the drawings to A3 size (A0 or A1 is more usual) and considering the sequence of drawings to minimise the need to consult several plans at the same time to execute a specific task.

The simplification and standardisation attained by the company also facilitated the development of partnerships with certain suppliers, taking advantage of its production scale to bargain for better conditions. For materials and components, the company concentrated on establishing partnerships with renowned suppliers in the market. These suppliers were used in order to obtain better purchase conditions and, in some cases, as a marketing tool, ensuring clients that their apartments would be built with recognised brand materials. For design suppliers, the company partnership strategy proved to be more comprehensive. In the case of partnerships with outsourced designers, the company developed a series of standardised design solutions and design presentation standards. These developments helped to simplify the works and guaranteed greater process repetition, besides making designs more transparent, convenient and better suited to the worksite environment.

The existence of these partnerships did not at all presuppose an equality relationship among those involved. In this case study, the contractor exerted its significant bargaining power on the designers (and also on subcontractors) and effectively moulded partnerships according to its strategies and convenience. So in many respects it was an unbalanced partnership arrangement, although it appeared to work for the parties involved.

In Company A, coherence among the product briefing (i1), the concept design and the product design (i2), as well as the coordination of the architecture and engineering designs, was primarily sought in the design standards and in the basic pre-established briefings and concepts. Interface i3 was simply solved as a matter of technological standards and design patterns. Design for production was a function particularly well performed, due to standardised design detailing that was conceived in order to improve buildability and reduce costs. In brief, the company was successful in developing products aligned with its business strategy, defined to serve and satisfy its clients with low-cost construction but highly functional apartments, which illustrates successful alignment of Ap and Ac.

Nevertheless, i4 and i5 were not specifically relevant in Case Study A, since there was no information flowing through these feedback interfaces, mainly because of the short period of time after implementation.

Case Study B

Company B was relatively new, having started as a building and real estate company in 1990 and as a constructor and real estate developer in 1993. It acted in several market segments (residential and commercial condominiums, flats and hotels), and its actuation in building construction and real estate projects was analysed, outside of the case study. In general, the construction and real estate projects developed by the company were directed toward the high-middle class segment and were located in prosperous regions of the city.

Case Study B demonstrates the cross-fertilisation between the production strategies (i3) and the practices and design management (i1 and i2), and also in the competitive strategy of construction and real estate companies in the market (Ac and Ap). It was clear that the introduction of innovative construction practices demanded new organisational strategies in the design flow and in the management of the participating designers. The introduction of innovative technologies in building construction is increasingly linked to an integration process between design and the construction site, as well as between managerial strategies and constructive technologies. However, interfaces i4 and i5, as well as the use of ICTs, were particularly less developed, as discussed below.

The company presented a production strategy and constructive options relatively differentiated from the practices found in the market. These technological options aimed to meet the production strategy of eliminating interferences in the work between construction subsystems in order to increase productivity, to simplify planning and the actuation of work teams and, depending on the project, to increase the speed of the works. To help achieve this, the company developed a series of specifications for product development.

At the interface with the market the company sought to couple its technological options to meet demand characteristics, by means of a product differentiation strategy, with solutions such as using broad spans between columns, ribbed slabs and internal walls in dry plaster, to provide more flexibility and choice to clients through the possibility of choosing from different plan options (a very valued attribute in the São Paulo City market).

In the residential condominiums, the company favoured the adoption of reinforced concrete structures moulded in situ, with massive external wall solutions (not common in Brazil), central pillars of medium/high performance concrete and flat ribbed slabs. In some commercial buildings, solutions were also developed with concrete or steel structures (column and beam) with external walls in concrete, premoulded panels and ribbed slab or steel deck.

As to fittings, the company favoured the use of innovative solutions using blinded bar systems (Figure 6.4, photo b), remote energy measurement (Figure 6.4, photo c), adoption of flexible hydraulic piping – PEX (Figure 6.5, photo b), being the hydraulic and sanitary fittings allocated in accessible shafts (Figure 6.6, photo a) and connections with the use points, developed to prevent built-in passages in the walls, using the horizontal sub-ceiling and vertical plum lines hidden in cupboards and carcasssing (Figure 6.6, photo b) so as to facilitate maintenance and repairs. The horizontal passage of electrical circuits was also developed in the sub-ceiling (adopted in all environments of the unit) to reduce interferences between the slab subsystems and electric fittings (Figure 6.3) and preventing the need for overlapping slab assembly teams with the electrical team. The results were an expanded work productivity and waste reduction by means of a clear rationalisation and industrialisation strategy and eliminating interferences between work teams.

In order to show these solutions, conventional worksite systems are illustrated in Figures 6.3–6.6 compared to the innovative systems used by Company B.

Following these principles, the company used subcontractors to deliver most of the work. The contracts established the execution of full subsystems (structures, dry-wall sealing, electric and hydraulic fittings, etc.), sometimes involving the supply of the necessary materials. Each subcontractor was allocated a worksite area where they should develop their storehouses and small production centres, as well as inventories when these were not distributed to the use sites, using the just-in-time (JIT) principle. Thus, teams of hired companies conducted most of the work and the contractor's personnel took charge of safety, follow-up, control and management of the worksite. As an example, in one of the sites visited around 200 outsourced workers were working concurrently, managed by a team of about 15 people employed by Contractor B.

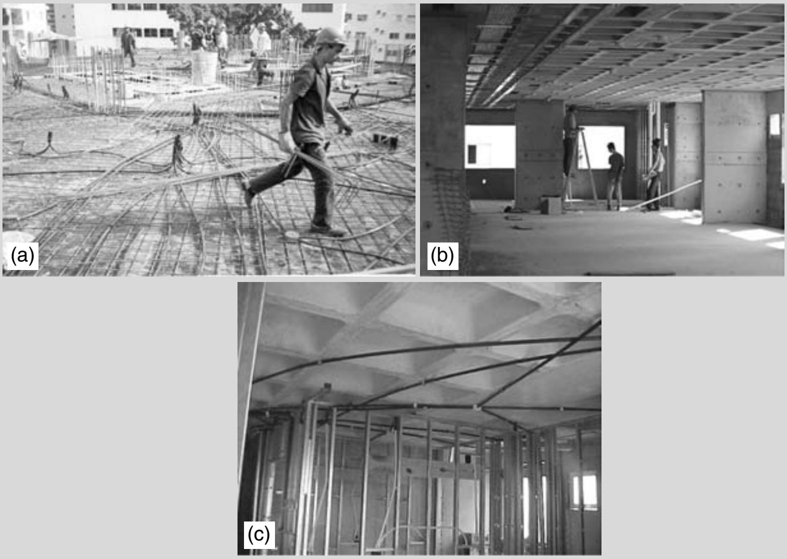

Figure 6.3 Conventional slab with inbuilt fittings (interferences) between reinforcing, concreting and electrical teams (a) versus ribbed slab with fittings passing through the sub-ceiling (b) and dry walls (c).

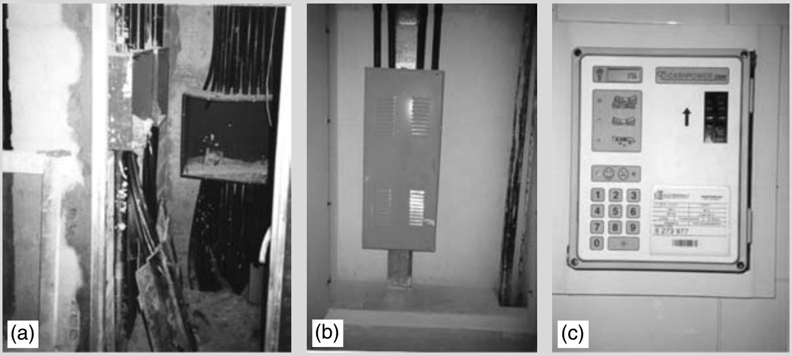

Figure 6.4 Vertical plumb lines and pull boxes: conventional solution (a) versus the solution used at the company's worksites (b) and box for remote energy measurement (c).

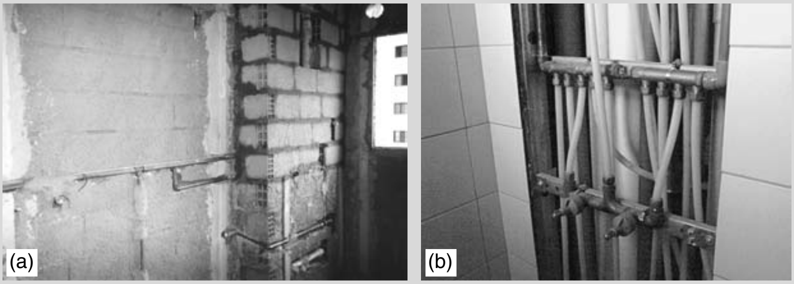

Figure 6.5 Conventional solution for distributing cold water (a) versus the solution adopted by the company using flexible piping (b).

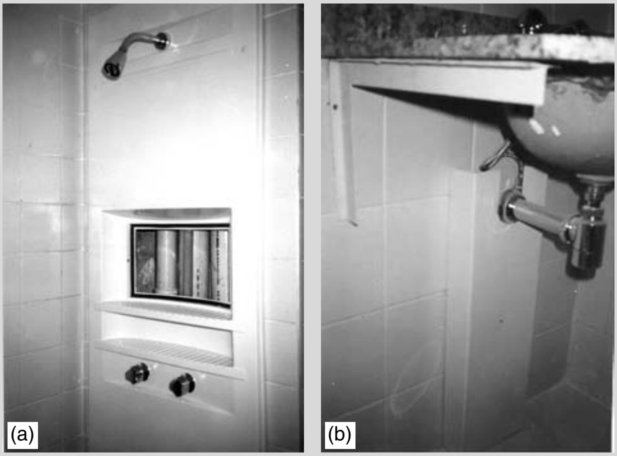

Figure 6.6 Solution used by the company for hydraulic fitting distribution protected by plastic moulding in order to facilitate inspections and maintenance – shaft (a) and lavatory sewage (b).

The production solutions adopted required a number of guidelines provided by the contractor company to the hired designers, who had to develop solutions compatible with the technology chosen by the company. This implied partnerships between the company and different designers which could be seen as engineering designer partnerships, since the solutions adopted required an adaptation of the conventional design practices to meet the company's needs.

The strategy of eliminating interferences between production teams challenged designers with the need to develop better-coordinated solutions to foresee the interfaces between subsystems. This demanded greater interactivity between designers from different disciplines and also caused changes in the flow of design detailing. As observed on site, the coordination of the designers was assigned to a single design coordinator from each contractor's design department. These coordinators acted in the product design phase and were also responsible for conveying the designs to the worksite, following up the work and attending to the occasional needs for re-adapting designs. They were also responsible for carrying out the updating of design documentation to create the 'as built' project information.

Because of the complexity of the project an external professional was hired to check the compatibility of the different design packages. This professional's work was restricted to the product design phase only. Exchange of information among designers, involving CAD documents, product description and specifications in other digital file formats, was aided by a centralised design management project website package hired from a specialised supplier in the construction market.

To explicitly show design progress the company developed a reference flowchart for developing its products. Design coordinators for each new project adapted this master document to suit their project characteristics. The flowchart was oriented by the design disciplines' scope of work and was subdivided according to the maturity of the solutions, with validation gates for the phases, generally linked to the design team meetings. The meetings, according to the stage of the project, could be held in person or by using the project web. This system of interaction among designers started soon after the preliminary design, assembly and feasibility study of the project. However, it did not consider the choice of sites and did not contemplate the first phase of product design, leaving an important part of the product development process fragmented.

At the interface between design and the construction site (i3) the flowchart considered some activities linked to design for production of the sites, which were part of the product development process and contributed to improving buildability. Indeed, the adoption of some technological or construction options, such as using prefabricated elements, combining monolithic concrete walls with structural function and external sealing, required the designers to take these solutions and the multiple interferences into account from the very beginning, such as detailing the framework span together with the development of the structural solution. Conversely, the use of dry-wall internal divisions, accessible fittings

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concealed by workbenches, careenings, ceilings, shafts, drilling on slabs instead of marking the drilling before concrete placement, etc. allowed some design detailing to be postponed and decisions could even be taken while the work was ongoing without causing any waste or rework. For example, once the electric and hydraulic vertical plumb lines were defined, the final definition of light and socket points and the type of basin and its exact positioning could be postponed, since the necessary fittings would all be installed in dry walls or the suspended ceiling.

Discussion and conclusion

Case Studies A and B illustrate innovation in the practices and products generated by the construction industry and the consequent adaptations and enhancements in PDP practices. This illustrates the pertinence of new models for managing and organising the product development process in the sector. It was found that the companies expanded the relationship between product design and production design. This suggests, at least in one of the cases, innovation in the process of commercialising a product and, in the other, the introduction of new constructive technologies and innovation in the building production planning and organisation.

In Case Study A the main product innovation was aimed at commercialisation and at the interface between the company and the market (Ac and Ap; i1). To facilitate better commercialisation the product and its production processes were reconfigured to better match the worksite flow (slower) with the payment capacity of the clients in the lower-middle class market niche. The product development process management of the company was shown to be conventional, in spite of innovations in the product and in the production process. Nevertheless, there were greater concerns and valorisation of designs in relation to traditional practice in the construction industry. Case Study A provided a good illustration of how interface i1 could be developed in practice. In Case Study B the company, acting mainly in the high-middle class niche, developed a technological innovation and productivity expansion strategy, seeking, by means of designs and specifications, to eliminate overlap between the constructive subsystems and to simplify the work. In this case the interface i2 was simplified by standardisation and i3 was deeply developed.

In both cases, the value of coordination between product designers (engineers and architects) can be observed, as well as a clear partnership strategy between the construction companies and their design suppliers (mainly the designers of the more technical and specialised disciplines). This finding highlights the relevance of implementing the interface i2. The two companies are recognised for delivering successful projects, which stems from their competences in managing interdisciplinary product design, which was one of main elements in their competitive strategy. On the other hand, in these two case studies the interfaces i4 and i5 were only slightly identified. Another finding concerns information technology use, as an important tool to improve the flow of design information throughout the product life cycle. Some companies are raising its use, but a large number of available solutions remain to be explored, mainly seeking to learn what can be improved by implementing i4 and i5.

Even though both companies presented improvements in their product development processes, it is possible to state that such evolutions occurred empirically, and that no systematic design or integrated PDP approach was observed in the companies. These companies structured their PDP based on references to practices elected in other industries, which demonstrates the pertinence of using managerial solutions and support tools for the design process of the building construction industry. Nevertheless, in these two companies more evolution of the interfaces is necessary if a total concurrent design process is to be achieved. Feedback can be provided for future product development (i5).

It is relevant to consider the applicability of the findings from the case studies and the application of the model outside Brazil, and even outside São Paulo. The main characteristics of the Brazilian construction sector include intensive manpower use, a low level of construction standardisation and strongly separated design and construction stages. Construction in São Paulo shows a very clear trend of changing from the use of intensive manpower to increased specialisation (of trades and technologies) and increasingly more use of standardisation, which is resulting in very productive work. The trend is also away from separated stages to more integrated management of the stages. In this sense (in a simplified view), São Paulo can be considered as a 'developed Brazil' inside an underdeveloped country. These characteristics turn the biggest Brazilian city into a kind of 'improvement laboratory' that serves as source of innovation to the rest of the country. The design information tends to be very detailed and extensive, partly to replace missing construction standards and partly to facilitate integration between the design and construction stages. Although this may be seen by some as overdetailed information, the result is improved quality control of workmanship/subcontracted work and improved productivity compared to projects with less extensive information.

Concerning different construction contexts, some elements should be taken into consideration in order to adapt the proposed reference model. These elements should include, besides manpower and management characteristics, the extension of project players' responsibilities. Nevertheless, the authors do believe that the main contents of the model are of universal application in building construction. Further applied research is required to test this assumption.

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