REDESIGNING THE PRODUCTION SYSTEM TO INCREASE FLEXIBILITY IN HOUSE BUILDING PROJECTS

Fábio K. Schramm[1], Patrícia A. Tillmann[2], Letícia R. Berr[3] and Carlos T. Formoso[4]

ABSTRACT

New market requirements have demanded from industrial companies innovations in their production strategies. Mass customization is one of those innovative strategies. It combines low unit costs of mass production and product flexibility. The ability of giving to the customer the possibility to choose among several product options has also been used as a competitive advantage in the housing building sector. However, despite the growing demand for customized homes, construction companies have faced difficulties to meet clients' needs with efficiency. One of the main causes lies in the fact that most companies do not change the way project production systems are designed to cope with the customization process, leading to an increase in site rework and waste. This paper presents a research study carried out in a housing building company, which has decided to introduce a customization strategy. The production system was redesigned based on lean principles to support that strategy. This article discusses briefly different approaches for customization, as well as the implications for the design of production systems. Also, the process of redesigning production systems based on lean principles is described. Key decisions and difficulties of this process are also highlighted. The results show that the consideration of lean principles in the production system has enabled not only the delivery of a more flexible product to customers, but also has improved the way production was managed due to an increase in transparency and predictability.

KEY WORDS

Production system design; flexibility; repetitive projects.

---

[1] MSc, Assistant Professor, Faculty of Management, Federal University of Pelotas (UFPel), PhD Candidate at NORIE/UFRGS, fabioks@ufpel.edu.br, Rua Almirante Barroso, 1734, CEP: 96010-280, Pelotas/RS, Brasil, Phone: +55 53 3222 7981

[2] Architect, PhD Student at NORIE/UFRGS, patriciatillmann@gmail.com

[3] Civil Engineer, MSc Student at NORIE/UFRGS, leticia.berr@ufrgs.br

[4] PhD, Associate Professor, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), formoso@ufrgs.br, Av. Osvaldo Aranha, 99 – 3º andar, CEP: 90035-190, Porto Alegre/RS, Brasil, Phone: +55 51 3308 3959

INTRODUCTION

In manufacturing, new production philosophies have allowed the development and implementation of the customization strategy, which supports the achievement of high-value added products within short time frames and at relatively low costs (Davis 1987, Pine 1994 and Piller 2003). Although customization has been widely used for competitive advantage in manufacturing, in the construction industry such approach has been mostly limited to some industrialized building systems.

In Brazil, where housing projects are produced through traditional craft-based construction processes, companies have been criticized for the lack of effectiveness in dealing with customer diversity. Managing the customization process was found to be one of their main difficulties, leading to higher construction costs due to an excessive waste of materials and low rates of productivity (Brandão 1997). However, there is a belief that adopting a customization strategy in the housing building industry might be a way to better achieve costumer's needs (Barlow 1999 and Leite 2005).

Changes in both product development and production system design processes are necessary in order to put that strategy in practice. According to Slack et al. (1997), while product development has the responsibility for speeding up and giving flexibility to production processes by using strategies such as modular design, production system design influences it by making products flow faster and by allowing processes to be easily reconfigured. Moreover, production system design is the first opportunity to tackle inherent variability of production systems, making them more reliable (Koskela 2000).

In order to change from a standardized to a customized and flexible approach it is necessary to introduce some changes on the product's design and its production system. Thus, the aim of this paper is to explore the possibility of introducing such changes in order to achieve a more efficient customization process. A case study was carried out in a small sized construction company, in which changes in the production system design was devised considering: (a) a customization process during the production stage by giving to the costumer pre-defined configuration alternatives; (b) a customization process at the delivery point through additional work; and (c) a customization process performed by costumers throughout the product's life.

MASS CUSTOMIZATION

The term mass customization (MC) was first coined by Stan Davis in 1987, referring to the strategy of reaching a larger number of customers, like in mass industry, giving them an individual treatment, like in craft production (Davis 1987). This concept has emerged in the late eighties and may be viewed as a natural follow up to processes that have become increasingly flexible and optimized regarding quality and costs (Da Silveira *et al.* 2001).

Levels and practical approaches for MC could vary according to the value chain configuration and the process stages involved in customizing the product (Lampel and Mintzberg 1996), as shown in Figure 1.

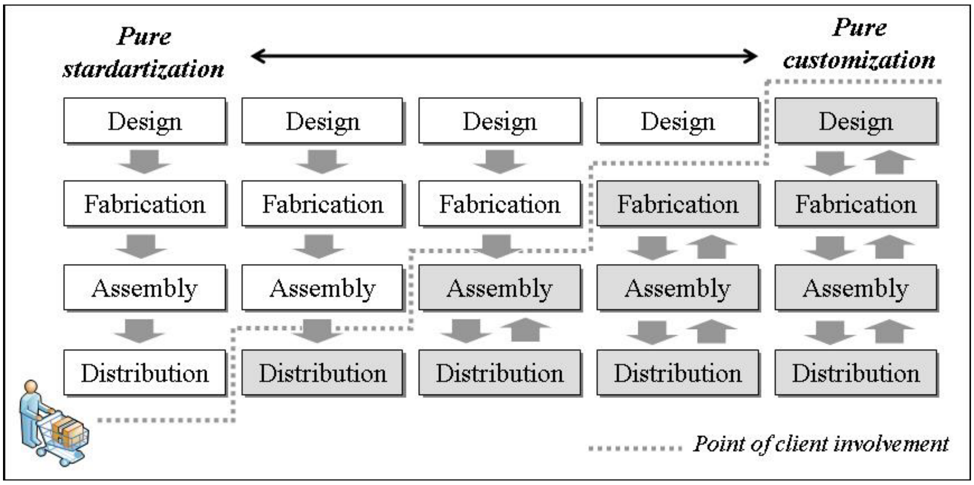

Figure 1: Customization Levels (Adapted from Lampel and Mintzberg 1996)

Thus, the earlier the customers take part in the process, the higher degree of customization that can be achieved (Duray et. al. 2000). When product customization occurs during the production stage, allowing customers to choose among some pre-defined design solutions, or even by adjusting the design to some extent, a lower degree of customization can be achieved (Lampel and Mintzberg 1996, Duray et al 2000). Moreover, products may also be customized at the delivery point through some additional work (Duray et. al. 2000).

The literature emphasizes that an increase in flexibility and agility of the production process played an important role to enable MC (Barlow 1999; Naim and Barlow 2003). A shift in the production paradigm and the development of just-in-time production, lean manufacturing, time-based competition and other advantages that came along with that new production philosophy have allowed companies to increase product variety at relatively low costs (Pine, 1994).

Flexible production systems enable companies to explore an economy of scope. It means that the same system is able to produce a greater variety of products, in a production line that could be easily reconfigured while still exploring economy of scale (Szwarcfiter and Dalcol 1997). Moreover, flexible systems allow a quick response to market (Stalk and Hout 1990).

Flexibility has been achieved since the introduction of the Toyota Production System, through the development of principles such as lot size, setup time and changeover reduction (Szwarcfiter and Dalcol 1997). Other factors have also contributed for more flexible systems such as multi-skilled workforce (Upton 1995), process transparency, lot size to closely match demand and the postponement of customization (Stalk and Hoult 1990; Child et al. 1991 *apud* Koskela 2000).

According to Christopher (2000), postponement or delayed configuration is a vital element to achieve agility. Modules and components of the product are produced to stock, but final assembly or customization does not take place until customer requirements are known. By doing that, inventory can be held at a generic level while final assembly can lead to a variety of end products. This shift moment from producing to stock and pulling production to meet a customer's requirements is called the decoupling point or the order penetration point (Sharman 1984 *apud* Christopher 2000). Postponement brings the decoupling point closer to final customers enabling customization to be achieved within a very short time frame, giving a quick response to market (Christopher 2000). The same author suggests that information technology (IT) has playing an important role in enabling such processes by providing a visibility of demand and sharing information. Thus, IT could enable process integration and collaborative work (Yassine 2004).

PRODUCTION SYSTEM DESIGN

Despite the importance of product design in the introduction of customization, production system design also play a key role on the implementation of that strategy. According to Askin and Goldberg (2002), "production system design and operation involve managing production resources to meet customer demand".

There are three main goals in designing production systems: (a) deliver the project, (b) maximize value, and (c) minimize waste (Koskela 2000). Although both deliver the project and minimize waste are very important goals, maximizing value to the customer has special importance in the context of this study.

Ballard et al. (2001) state that one form to maximize value is delivering products that enable customers to better accomplish their purposes by: (a) structuring work for value generation; (b) understanding, critiquing and expanding customer purposes; and (c) increasing system control (ability to realize purposes). Besides the Value concept, it is also important to consider the impacts of Flow concept on Value concept. Thus, according to Koskela (2000), more flexible production systems can allow the satisfaction of more variable demand pattern.

Regarding the decisions involved in designing production systems, a model was presented in the 2004 IGLC Conference (Schramm et al. 2004) for the production system design of low-income housing projects. That model intended to guide the decision making during the structuring process of the production system, stressing the design of a continuous production workflow, and the management of hand-offs between crews. Figure 2 presents the main steps involved in designing production systems in that model.

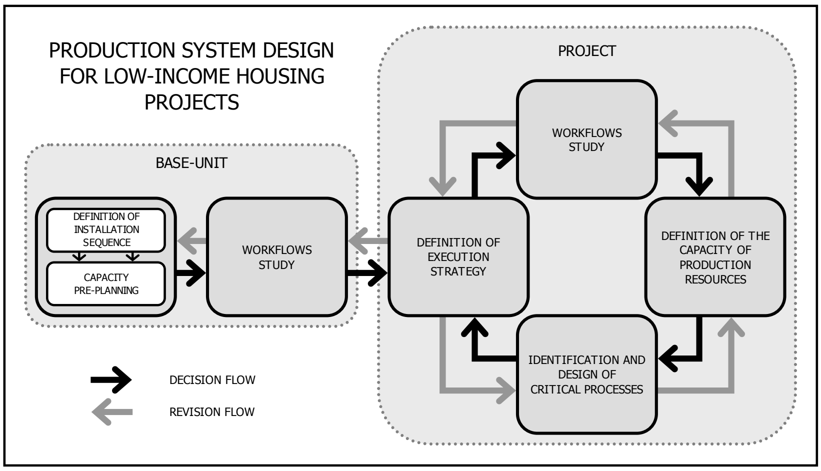

Figure 2: The Model of Production System Design for Low-income Hosing Projects (Schramm et al. 2004)

This model establishes six main steps for production system design: (a) definition of the base-unit installation sequence and capacity pre-planning; (b) study of base-unit workflows; (c) definition of the execution strategy; (d) study of project workflows; (e) definition of production resources capacity; and (f) identification and design of critical processes.

In spite of the sequential representation of those steps, the decisions are usually interdependent. For that reason, several iterations are usually necessary (represented by decision and revision flows), as indicated in Figure 02.

Another paper in the 2006 IGLC Conference presented an adaptation of that model to the context of complex industrial and commercial building projects (Schramm et al. 2006). One of the main conclusions of that paper was that in those projects production system design also requires as an input information about client requirements, especially those concerned with the delivery of the project.

Thus, in a customized production system its design should take into consideration how to reach those objectives at the two levels proposed by Slack et al. (1997): at the strategic level, focusing on the broader chain of processes that involve not only on-site production but also suppliers and customers; and at the operational level, devising the layout and the material and information flows to create favorable conditions for a higher performance.

RESEARCH METHOD

This paper presents a case study that was carried out by two researchers with different but complementary research objectives. One of them was interested in designing the production system of the company while the other was trying to identify opportunities for that company to adopt a customization strategy. The main objective of this paper is to describe and discuss the process of redesigning the production system of a housing building company in order to improve the company's ability to deal with customer diversity.

This case study was carried out in a small construction company located in Canoas, in the Metropolitan Region of Porto Alegre, in the South of Brazil. This company has been involved in the development and construction of house building projects for lower middle class customers, who are entitled to acquire their house through a governmental housing program. Being part of that program, the company should develop the housing schemes, as well as gather and bring in groups of potential customers to the financial institution. By doing that, the company would receive an amount of money necessary to start producing the project. By each group introduced in the process (at least five clients), the amount of money necessary to build their houses was released. The housing project was, therefore, divided into phases that could be built in sequence.

Since dwellings were usually sold after the design stage and before they were built, customers were allowed to adapt the project to some extent in order to better suit their needs. However, the company had recently decided to build some dwellings to stock, in order to avoid losing potential clients that do not want to buy only a dwelling plan. Consequently, customers who bought the house before the production phase were able to customize it, while those who entered in or after dwellings were built received a standard house.

Moreover, the new production process should cope with the customer entering throughout the entire production process. Thus, the customization degree could be increased by allowing product adjustments not only during the production phase (through some pre-defined design solutions) but also at the point of delivery, allowing the customization of those standard houses that were built to stock. In order to achieve such a process, this study focused on two main issues: the production system design itself and the communication system that was necessary to support that process.

The project investigated consisted of a low-rise terraced housing project which was made up of 112 ninety square-meter two-story houses, grouped into 21 blocks of 4, 8 or 10 dwellings. The main construction techniques used were: load-bearing concrete block walls, pre-cast concrete slabs and ceramic roof tiles.

Ten two-hour weekly meetings were held to devise the PSD (production system design) of the project. Besides the research team, the production engineer and the project designer took part in the meetings and, when needed, key suppliers and subcontractors were also invited to participate.

The study was divided into two stages. Firstly a survey with the owners of previous company projects was carried out in order to assess their satisfaction level and to identify the main changes they had made or would like to make in the future in their dwellings. Based on the survey's outcomes, a list of the most cited design changes was presented to the company's management team that analyzed them and defined those that would be considered in the customization process.

Secondly, the research team started to redesign the project production system in order to make it possible to implement the customization strategy according to the previously mentioned PSD model.

Also, in that case study, discrete-event simulation was used in order to improve the PSD decision (the main findings of that use will be described in another paper in this Conference).

CASE STUDY

COMPANY'S REQUIREMENTS

As mentioned earlier, the main strategy of the construction company to implement the customization approach was divided into two parts. Firstly, the company should be able to deal with the entrance of customers specifications throughout the entire production stage when the customer could choose some predetermined house changes.

Thus, if a customer bought a house in the beginning of the construction phase, it would be possible to change a larger number of features than if he did it after the basic house had been finished, when he could just choose between some finishing options. Finally, the customer could buy a standard house and customize it through some additional work.

PRODUCTION SYSTEM DESIGN

The design of the production system started by defining the sequence of construction stages of the project. In order to make the first type of customization possible it was necessary to establish a series of milestones that defined the last possible moment when the customer could change some of the predefined house's features. Thus, it was very important to establish a sound construction sequence, since changes in that sequence could affect those milestones.

Although the construction sequence was based on previous projects' experience, often that sequence was not followed in practice in those projects. Thus, a set of 10 meetings was held until a standard construction sequence could be established. Besides the researchers and the production engineer, the foreman and main subcontractors took part in the meetings as well.

In addition to the construction sequence, an expected cycle time (expressed by a triangular time distribution) was also defined, as well as the production and transfer batch sizes and the work crew size for each process. After reaching an agreement on the most suitable sequence, those decisions were recorded in a document and sent to the construction site to be posted at the site's office.

Based on the changes that would be allowed to the customers, some customization points were marked on the construction sequence. Those points represented the last possible moment for customers to request a specific set of changes. As previously mentioned, the earlier the customer bought the house the larger the possibilities of specifications changes. At the end, a set of five customization points was defined.

Figure 3 presents part of the construction sequence with one of the five customization points.

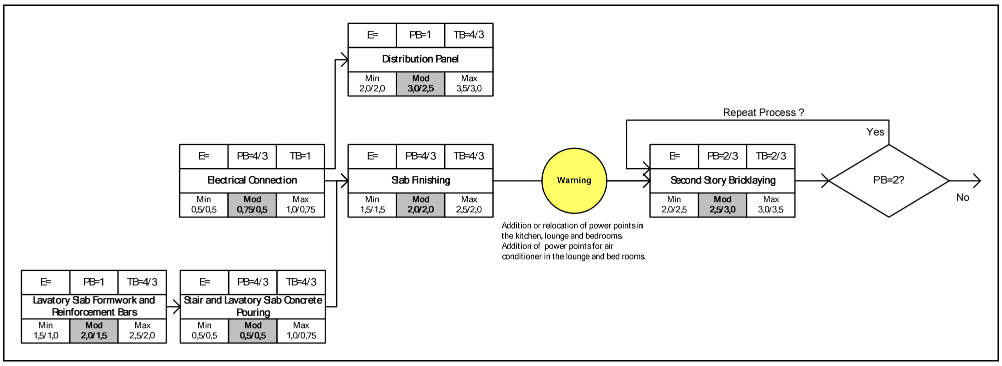

Figure 3: Changes Allowed During the Construction Phase

Besides those points, a set of customization alternatives were defined to be put in practice if the customers bought the house after the standard house was finished. Thus, at that time the customer could change some finishing specifications.

Following the PSD sequence, the next steps were to study the workflows in the base unit and to define the project's execution strategy. The first was based on the construction sequence and on the processes' cycle times and batch sizes. The line of balance was used to make that clearer. The second was the sequence in which the dwellings should be produced.

Based on those previous decisions a simulation model was carried out. One of the main outcomes of that model was a line of balance, which was used to understand and discuss the intended execution strategy and main workflows. Figure 4 presents the line of balance devised from the simulation model[5].

[5] One of the advantages of using a simulation model in the PSD process is the possibility of considering the effects of variability on the production system.

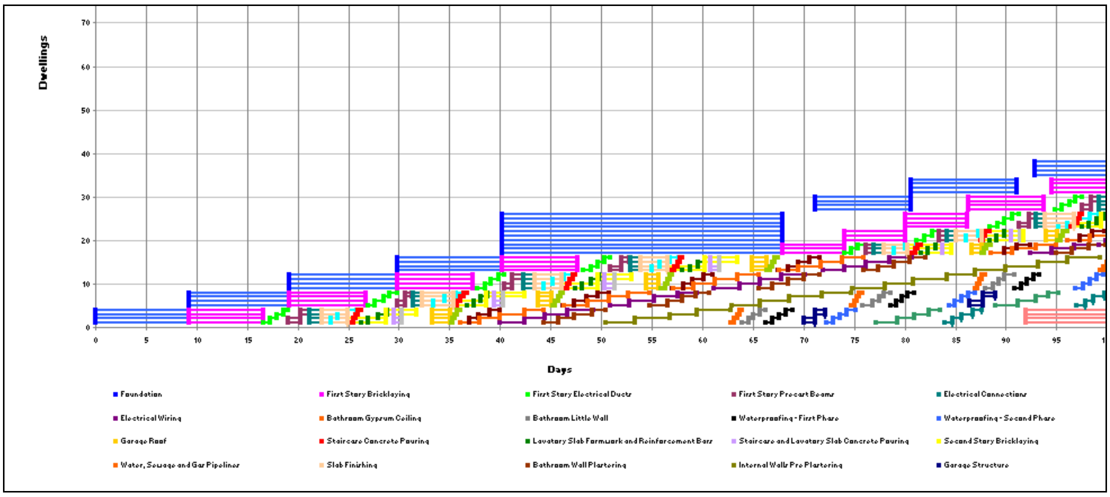

Figure 4: Line of Balance Used to Study the Project's Workflows

That line of balance was used to predict the customization points' deadlines considering not only the workflows study but also the chosen execution strategy. Thus, a spreadsheet with the deadlines of the five customization points of each dwelling was devised and used by the selling department during the buying process to inform the customers about the available customization options[6].

At the point of sale, the information about the customization points' deadlines was used to help customers making their choices, regarding flexibility and time of delivery. A brochure was developed (figure 5), containing information on how the production process works, the customization options in each stage and the deadlines for requesting customization in each stage. Such transparency with customers was needed to avoid expectations regarding product flexibility and time of delivery to be frustrated.

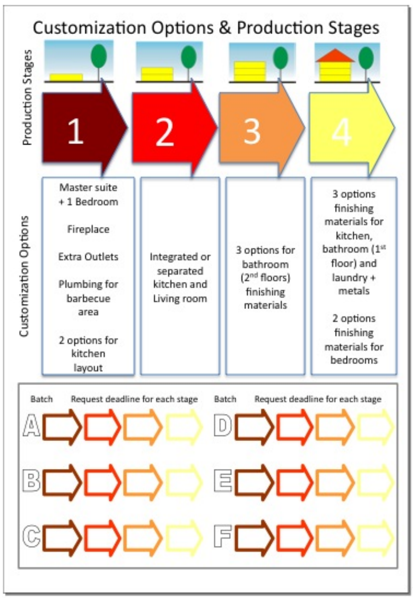

Figure 5: Brochure with Information About the Customization Process for Customers

6 During the production phase that spreadsheet should be updated to reflect real time situation.

DISCUSSION

After devising a customization strategy, several improvements were necessary in the production system Figure 6 summarizes the main changes that were introduced and compares them with the existing production system, that has been adopted by the company in previous projects, as well as the production management principles that were underneath those practices.

Previous Production System	Production System for Customization	Lean Principles Involved
All possible product changes should be made just after the construction phase finished	Some changes could be made during the construction phase while others could be made afterward	Process flexibility
Larger order batches of a type of material (e.g. ceramic tiles), batches sizes established by the suppliers	Smaller order batches, larger option of types, partnerships with more flexible and agile dealers	Reduction of batch size
All work crews were allocated to standardized operations and reallocated to the customization process without any previous criterion	Some work crews were allocated to the customization process according to the construction sequence	Predictability and Transparency
All processes were performed independently of the changes that could be made after the sale (rework if any change was chosen)	Some production processes were postponed to after the sale waiting for the customer requirements (no rework)	Non-value adding activities reduction, output flexibility
Modifications varied and depended on each customer's request	Modifications were predefined and each customer could just opt between them	Reducing variability
As the dwellings were produced in large production batches the amount of information on clients specification was larger and hard to manage	Smaller production batches make information managing easier and the customization process more effective	Batch size reduction
Product and production system design were independent activities	Designer and production engineer took part in the meetings and both design and production changes were discussed and implemented to allow that approach	Increasing output value by integrating product and process design

Figure 6: Comparison between the Production System Design before and After Adopting Customization Approach

Most improvements introduced were strongly related to principles that are often associated to Lean Production, such as flexibility, transparency, and batch size reduction. Therefore, the task of PSD has contributed to support the generation of high value added products at relatively low cost and within a short time frame through the reorganization of the production system.

The construction process was made more predictable since all customization options are previously known, making it easier to manage the product development process. Part of that predictability was due to the adoption of a standard construction sequence for the project. That decision played a key role in the implementation of the customization strategy. Based on the standardized construction sequence, the production manager knows in advance the amount of production resources required to perform each activity; suppliers were aware of all activities that should be performed along the construction phase and the moment when they are needed; and the foremen, subcontractors and workers could easily understand all steps of the process and their interdependency.

The PSD outcomes enabled the design of control tools focused on the customization process, which represented a unified and useful database to different actors in a collaborative environment, enabling the control of:

- The last responsible moment to accept client's requests for changes;
- The time to buy the materials used in the customization process;

- The amount of needed production resources for each activity during the whole project; and
- The effects of the changes on the production system performance.

CONCLUSIONS

In this paper, the role of production system design in supporting the adoption of a customization strategy was discussed. A case study was carried out and some were applied during the production system design phase in order to support that adoption.

Some advantages and difficulties to do that were also presented. One of the main advantages is related to the improvement of process transparency, since all of the involved actors could be aware of the construction stage and the possible customization degree at any time. One of the main difficulties to adopt a customization system is the lack of standardization of processes in construction industry. Thus, achieving standardization is one of the first steps to enable customization.

That was the first experience of the company with a customized project. Based on that experience the company intends to reapply it to future projects. One of the main benefits that have been perceived by the company's production team is related to the predictability of the changes, since they are restricted to a limited scope. That predictability allows planning the allocation of independent resources for the customization processes, reducing the negative impacts on regular workflows. From the customer's point of view the main benefits are also related to the predictability of possible changes, its costs and deadlines.

ACKNOWLEDGEMENTS

The authors would like to thank CAPES (PQI Programme), FAPERGS (PROADE3 Programme) and CNPq (PROSUL Programme) for the research grants and scholarships that supported the development of this research study, and also the construction company that was partner in this study.

REFERENCES

Askin, R. G. and Goldberg, J. B. (2002). *Design and Analysis of Lean Production Systems.* John Wiley.

Ballard, G., Koskela, L., Howell, G., and Zabelle, T. (2001). "Production System Design in Construction". *Proceedings of the 9th annual conference of the International Group for Lean Construction*, Singapore.

Barlow, J. (1999). "From Craft Production to Mass Customization: Innovation Requirements for the UK House building Industry." *Housing Studies*, Bristol, 14, (1), 23-42.

Brandão, D. Q. (1997). "Flexibilidade, variabilidade e participação do cliente em projetos residenciais multifamiliares: conceitos e formas de aplicação em incorporações". Msc. Diss., Civil Engrg., Federal Univ. of Santa Catarina, Florianópolis, SC 235 pp.

Child, P., Diederichs, R. and Sanders, F. (1991). "The management of complexity." *Sloan Management Review*, Fall, 73-80.

Christopher, M. (2000). "The Agile Supply Chain: Competing in Volatile Markets." *Industrial Marketing Management*, 20, 37-44.

Da Silveira, G., Borenstein, D. and Fogliatto, F. S. (2001). "Mass customization: Literature Review and Research Directions". *International Journal of Production Economics*, 72, (1), 1-13.

Davis, S. (1987). *Future Perfect*. Addison-Wesley, Reading, 243 p.
Duray, R., Ward, P.T., Milligan, G.W., and Berry, W.L. (2000). "Approaches to Mass Customization: Configurations and Empirical Validation." *Journal of Operations Management*, 18, (6), 605-625.
Gaither, N. and Frazier, G. (2001). *Production and Operations Management*. Pioneira Thomson Learning. São Paulo.
Koskela L. (2000). *An exploration towards a production theory and its application to construction.* Espoo 2000. Technical Research Center of Finland, VTT Publications 408. 296p.
Lampel J. and Mintzberg, H. (1996). "Customizing customization." *Sloan Management Review*. 38, (1), 21-30.
Leite, Fernanda L. (2005). "Contribuições para o Gerenciamento de Requisitos do Cliente em Empreendimentos do Programa de Arrendamento Residencial". M.Sc. Dissertation, Civil Engrg., Federal Univ. of Rio Grande do Sul, Porto Alegre, RS. 172 pp.
Naim, M. and Barlow, J. (2003). "An innovative supply chain strategy for customized housing." *Construction Management and Economics,* 21, 557–564.
Piller, F. "What is Mass Customization? A focused view on the term". (2003). *Mass Customization News (Newsletter)*, Munique, DE, 6, (1), 16 p. (available at: http://www.mass-customization.de/news/news03_01.pdf).
Pine II, B. Joseph. (1994). *Personalizando Produtos e Serviços*: customização maciça. Makron Books do Brasil, São Paulo, 334 p.
Roy, R., Brown, J. and Gaze, C. (2003). "Re-engineering the construction process in the speculative house-building sector." *Construction Management and Economics,* Reading, 21, (2), 137–146.
Schramm, F. K., Costa, D. B., and Formoso, C. T. (2004). "The Design of Production System in Low-Income Housing Projects". *Proceedings of the 12th annual conference of the International Group for Lean Construction*, Helsingør.
Schramm, F. K., Rodrigues, A. A., and Formoso, C. T. (2006) "The Role of Production System Design in the Management of Complex Projects". *Proceedings of the 14th Annual Conference of the International Group for Lean Construction*, Santiago de Chile.
Sharman, G. (1984). "The Rediscovery of Logistics". *Harvard Business Review*. September/October.
Slack, N. Chambers, S., Harland, C., Harrison, A. and Johnston, R. (1997). *Operations Management*. Atlas. São Paulo.
Stalk, G. and Hout, T. (1990). *Competing Against Time*: How Time-based Competition is Reshaping Global Markets (Free Press)
Szwarcfiter C. and Dalcol, P. R. T. (1997). "Economias de Escala e de Escopo: Desmistificando alguns Aspectos da Transição". *Revista Produção*, Belo Horizonte, 7, (2), 117-129.
Upton, David M. (1995). "What Really Makes Factories Flexible?" *Harvard Business Review*. 73, (4), 74-84.
Yassine, A., Kim, K., Roemer, T. and Holweg, M. (2004). "Investigating the Role of Information Technology in Customized Product Design", *International Journal of Production Planning and Control*, 14, (4), 422-434.