THE RELATIONSHIP BETWEEN PRODUCT ARCHITECTURE AND MASS CUSTOMIZATION IN HOUSING SECTOR

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ABSTRACT

In the housing sector, the search for improved productivity, agility in delivery and customer satisfaction happens due to increased competition among construction companies. This competition requires the development of new strategies such as mass customization to attend these requirements. Mass customization aims to meet a large number of consumers with an individualized approach while maintaining an efficiency similar to mass production. Modular architecture is an important support of mass customization as product variants are produced from a limited set of components (modules) which allows for production efficiency.

This paper seeks to analyze through a literature review and a case study, the relationship between product architecture and mass customization in housing sector. Initially, literature sources related to the topic, consisting mainly of books and scientific articles were selected. Next, the concepts of product architecture and mass customization and their contribution to the provision of housing developments are discussed. Finally, we developed a case study in a construction company located in Fortaleza/CE, implementing the strategy of mass customization in their endeavors. Whit this, are presented the main obstacles that the architecture product may cause the application of the mass customization strategy.

KEYWORDS

Mass customization, product architecture and product development.

INTRODUCTION

The transformations of social behaviour, the diversity of residents and profiles changes in lifestyle are factors that indicate the current heterogeneous realities and are the main causes of the need for change in the design of housing units (Brandão, 2002; Tramontano; Benevente, 2004; Rocha, 2011). As noted Galfetti[4] (1997, *apud* Brandão,

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[4] GALFETTI, Gustau Gili. **Model apartments: experimental domestic cells**. Barcelona: Editorial Gustavo Gili, 1997.

2002), the stereotypical housing, designed to a standard family, an average user, that never existed.

Unlike what happened with the sector of the construction industry, market saturation led to increased competition among manufacturing firms, changing the paradigm of mass production more geared to the needs of the consumer strategies (Lampel; Mintzberg, 1996; Szwarcfiter; Dalcol, 1997; Tillmann, 2008). The industry and service sectors recognized the segmentation of consumer profiles and that their needs differ by demographic variables, geographical location, economic resources, lifestyle and others, realizing the difficulty of continuing to exploit the economics of scale (Szwarcfiter; Dalcol, 1997; Canova; Hochheim, 2008).

Currently, this more flexible movement is a reaction to the significant economic and technological forces, as well as the standardization movement was in its time (Lampel; Mintzberg, 1996). Under this new perspective, Tillmann (2008) has listed some strategies of market segmentation, as well as related concepts such as: the logical of individualization (Lampel; Mintzberg, 1996); niche markets (Kotler, 1998); markets customization (Davis, 1987); individualized marketing (Rapp; Collins, 1990) and, by differentiation competition (Porter, 1980). The author states that these terms point to a shift in focus in marketing.

Among these new strategies, there is mass customization (MC), which refers to a strategy of customizations of goods and services with cost and schedule similar to standard products (Jiao; Ma; Tseng, 2001; Rocha; Formoso; Santos, 2012). Stan Davis was who first coined the term mass customization, in his book *Future Perfect*, published in 1987 (Duray; Ward; Milligan; Berry, 2000; Silveira; Borenstein; Fogliatto, 2001; Jiao; Ma; Tseng, 2001; Tillmann, 2008).

Since then, several areas such as operations management, supply chain management, product development process, product architecture, information technology and marketing discuss MC, but still no consensus on the limits and scope of the term (Jiao; Ma; Tseng, 2001; Rocha, 2011). Therefore, companies seeking to develop products with low production cost and high differentiation are adopting the strategy of MC in order to rapidly attend to customer and market demands.

Some efforts have been made to enable the adoption of MC strategy also in the construction industry (Tillmann, 2008). Some examples can be cited, such as production of prefabricated housing in Japan (Noguchi, 2003); mass custom design for housing in Mexico (Noguchi, Hernàndez-Velasco, 2005) and; housing sector's companies in the UK (Barlow; 1998; Rocha; Formoso; Santos, 2012). Several authors recognize the need to produce dwellings that meet adequately the needs of residents (Brandão, 1997; 2002; 2011; Tramontano; Benvente, 2004; Tillmann; Formoso, 2008; Xavier; Barbirato, 2011).

The product architecture is considered one of the key activities for the industrial development of products (Dahmus; Gonzalez-Zugasti; Otto, 2001). This concept ensures productivity while fulfilling customer expectations (Muffatto; Roveda, 2002).

Therefore, if the goal of the construction company is to adopt the strategy of MC for better results in relation to customer satisfaction, reduced costs and increased productivity, the product architecture should be contemplated if this goal to be met efficiently. The concept of product architecture (PA) is a way to facilitate the implementation of MC strategy (Du; Jiao; Tseng, 2001; Halman, 2008; Tillmann, 2008; Rocha, 2011).

In the construction industry, few studies have been conducted addressing the concept of product architecture as reengineering in the construction of the housing sector (Roy; Brown; Gaze, 2003); relationship between process modularity, functional coordination and MC (Hofman; Halman; Ion, 2008); the modular approach in Dutch houses (Halman; Voordijk; Reymen, 2008); tactics of MC for Brazilian housing production (Tillmann; Formoso, 2008); the relationship of supply networks for architecture modular product in the construction industry (Hofman; Voordijk; Halman, 2009); an overview of the strategies of customization in the construction industry (Rocha; Formoso; Santos, 2012).

METHODOLOGY

The research was divided into three stages. The first was a research strategy, a literature search performed as a way to understand the process of development of housing projects from the application of MC strategy using the concept of product architecture. This literature research was prepared based on previously published material. The material was selected based on the proximity and relevance to the discussed topic, performing a historical and current overview on the subject.

In second stage, project that used the strategy of MC was selected. At this stage, interviews with industry customization of construction and architecture firms responsible for the project were applied. Issues relating to the adoption of this strategy and mapping of the venture development process were addressed.

The last step was to analyze floor plans options offered to the customer. This analysis sought to identify the concepts related to product architecture. Finally, we analyzed the adoption of CM practices in product development, their main process obstacles, aiming at improving the use of this strategy.

LITERATURE REVIEW

In the twentieth century, the United States emerged in mass production, which has its precursor Henry Ford. This executive provided the conditions for the auto industry to be the most influential in the development of techniques of operations management (Correa, Correa, 2011). This means production of goods is based on production with stable flow in large scale and operational efficiency of the assembly line, specialized machinery and labor of workers through standardized products (Pine, 1994; Correa, Correa, 2011).

Henry Ford brought to the industrial environment, the principles of - division of labor, choosing the right employee for the job, joining them with the principles of interchangeability of parts produced in huge quantities automatically (Correa, Correa, 2011). Those authors also claims that Henry Ford added to these the idea of standardization of products and make products move up, while workstations were static.

Due to the success of mass production, which for so long controlled the world and increased the income of its practitioners, it was extremely difficult for administrators of the 1970s and 1980s realize that society was actually changing (Pine, 1994). To this author, the homogeneity of markets was challenged by changes in the needs and wishes of consumers.

The first attempts to resolve the conflict between the need for standardization to reduce costs and diversity in the format requested by consumers emerged in the mid-

1920s, Alfred Sloan at General Motors (Womack, Jones, Roos, 1990). Those authors claim that Sloan sought to reach different market segments by producing five different product models. However, the starting point for change in the paradigm of flexible production came with the development of industrial engineering at the car plant, called Toyota Production System, led by Ohno and Shingo in the 1950s in Japan (Koskela, 2000).

This new paradigm, called lean production, combines the advantages of mass and artisan production, while avoiding the rigidity of the first and the high cost of the second (Womack, Jones, Roos, 1990). These authors also stated that this new paradigm uses teams with multi-skilled workers at all levels of the organization, increasingly automated and flexible in order to produce volumes of products with huge range machines. In addition to these changes, we can also mention the elimination of inventories, reduction in lot size, reconfiguring the layout, greater cooperation between actors in the supply chain and reducing set-up time among others (Koskela, 2000).

The new production model has emerged from the growing trend for segmentation of consumer markets; increasingly away from the traditional markets of standard goods inherent to industrial paradigm based on mass production (Szwarcfiter; Dalcol, 1997). Those authors also argue that this phenomenon arose due to the increasing difficulty of firms to organize themselves along the lines of Fordism, with the exploitation of economies of scale through hard standardized equipment that produce goods in large lots to dilute the unit cost of the product and high investment in such equipment.

In the 1960s and 1970s, the market became even more complex and intense in competition, faster delivery of goods to customers became a muster (Shivanand; Benal; Koti, 2006). A customization strategy was formulated where companies had to adapt to a more flexible environment and meet different market segments, through its operations; this innovation is related to the effort to gain competitive advantage (Shivanand; Benal; Koti, 2006).

MASS CUSTOMIZATION

From the 1980s onwards, Pine (1994) points to the emergence of process that simultaneously combines mass production and customized production, called mass customization (MC). The adoption of this strategy can be seen as a natural evolution of the companies, as the processes became increasingly flexible and optimized for quality and costs (Silveira, Borenstein, Fogliatto, 2001).

The concept of MC refers to a strategy of providing customized products and services through flexible processes, at rates and terms similar to standard products (Duray, 2000; Silveira, Borenstein Fogliatto, 2001; Rocha; Formoso; Santos 2012).

The implementation of this strategy and related principles must be aligned with the organization strategic goals and processes. A strategic definition of customization depends on the particular environment each company operates (Rocha, 2011). The author states that there is not only one customization strategy, there are many that can be developed based on a MC approach.

The increasing demand for variety and flexibility encourages companies to consider building new housing projects, types of products and processes (Halman; Voordijk; Reymen, 2008 Hofman; Halman, Ion, 2006), creating a closer relationship

between client and company, which now includes requests for design changes. This has become an emerging condition in the production process for the construction industry: the personalization and choice (Brandão, 2002).

Currently, construction projects are organized in chains of temporary supply with direct implications in strategies of customization that can be developed (Koskela, 2000; Rocha, 2011). Accordingly, Rocha (2011) states that it is unlikely that a single strategy is used for customizing a large volume of products as in the manufacturing sector, because these strategies vary from one project to another, depending on the specific goals and stakeholders.

In the construction industry, some research addressed the concept of MC, such as re-engineering in the construction of the housing sector (Roy; Brown; Gaze, 2003); relationship between process modularity, functional coordination and mass customization (Hofman; Halman, Ion, 2006), the modular approach in Dutch houses (Halman; Voordijk; Reymen, 2008); tactics of mass customization for Brazilian housing production (Tillmann; Formoso, 2008), the relationship of supply networks for modular product architecture in the construction (Hofman; Voordijk; Halman, 2009); industry an overview of the strategies of customization in the building sector (Rocha; Formoso, Santos, 2012).

However, some changes are suggested for improving the implementation of this strategy, such as: creation of standards and internal company procedures, better coordination between projects, deadlines for changes requests, limiting choices (Brandão, 2002), changes in the product development process, supplier involvement in customization, improved information management and planning in the production process (Tillmann, 2008).

PRODUCT ARCHITECTURE

Determine the Product Architecture (PA) is one of the key activities for any industrial action in product development (Dahmus; Gonzalez-Zugasti; Otto, 2001). This activity must ensure productivity and at the same time ensuring that the products meet the expectations of customers in terms of technical performance, innovation and delivery time (Muffatto; Roveda, 2002).

For better understanding the PA concept, some definitions found in the literature are described below:

- Wang et al. (2010, cited Rocha, 2011) defines PA is a conceptual representation of the physical components used to manufacture a product, along with the interactions between them, that affect the operation of the product;
- Rozenfeld et al (2006) defines PA that as how functional elements, i.e., systems, subsystems and components are arranged and how they relate through their interfaces;
- To Ulrich (1995), PA is the method by which the function of a product is allocated to its physical components. That is, as the functional elements, through a mapping of the physical components and their specifications will interact through their interfaces.

According to Ulrich (1995), the functional elements can be translated in form of diagrams, which describe the structural function of the product. In the case of a housing project, the functions required by a unity are identified (i.e. sleeping, eating, dressing, and studying among others). From the identification of functional elements, map the physical components, where component is the physical part or separate subset, distinct from any part of the product, allowing their inclusion, withdrawal or amendment (Ulrich, 1995) (i.e. rooms that can be added, withdrawn or modified in a choice of plant as a bedroom, bathroom, office, closet, kitchen among others). In the next step the interaction among these components through the interfaces are determined. To the author, these interfaces may involve geometric or no contact interactions (i.e. the rooms can be interconnected through doors, hallways, walkways, masonry among others).

Ulrich (1995) also states that PA has two types: modular architecture and integral architecture. Modular architecture exists in the mapping one-to-one from the functional elements to physical components (Ulrich, 1995; Salvador; Forza; Rungtusanatham, 2002). Rocha (2011), in turn, said modular architecture in which two or more physical components play more than one role, or two or more functions are performed by a single component. Integral architecture exists in a complex mapping (not one-to-one) of the functional elements to physical components and connection of components through interfaces. To Rocha (2011), this type of architecture is not suitable for customization strategies, once its requires a product designed from scratch for each order, jeopardizing costs and delivery times similar to MC products. Although most of the products cannot be classified strictly as modular and integral, the project can take different architectures (Rocha, 2011).

One implication of this concept is that, to the extent that different segments of the market require slightly different products, products variants of each segment may differ in one or more modules; the rest of the product remains unchanged (Salvador, 2007). Thus, the author states that the purpose of product modularity is to have different products, with minimal differentiation.

Associated with PA, there are also other guidelines and concepts that support the use of MC and can be applied in the housing sector. Among them, we highlight:

- Flexibility and Postponement: Allow production systems to handle product variants created under the strategy of customization. (Feitzinger, Lee, 1997; Rocha, 2011);
- Plataform: The term refers to the specific platform configuration of a production system to generate easily from it the desired range of products. The use of the platform allows you to tailor products to specific customer groups in order to increase their satisfaction (Mufatto; Roveda, 2002; Halman *et al.*, 2003; Halman et al., 2008)

CASE STUDY

The company chosen for this study is a company, developer and builder, part of a business group, founded in 1977 in the city of Fortaleza, state of Ceara/Brazil. It is ISO 9000 certified, and implements lean construction philosophy. The company primarily operates in ventures that are characterized by vertical housing buildings, and during the study were 6 projects running. A work consisting of two towers

multifamily buildings (A and F), located in Fortaleza, whose main characteristics are described in Table was analyzed.

Table 1: Key features of the project.

Type	Residential
N.° towers	2
No floor/ towers	22
Units / floor / towers	2
Total of units	84
Area of apartments (m^2)	160,03

After the pre-launch stage, two plan options were presented, in addition to type plan. These options are offered by the company, attending a practice applied to product development, with no increase in the total projects costs. It has been found through a survey done by the company that most customers opted for MC (45.7% in Tower A and 52.5% in F tower). According to type plan, called Family and other two options, called Grand Family and Petit Family, respectively.

Product development is described with information collected after an interview with the designer and builder, which identified, mapped and sequenced the macro process steps described below:

- Acquisition of land;
- Hiring the architectural firm;
- Development of the Preliminary Study of the development and the plan with the Family option;
- Pre-launch of the project;
- Define the type of customization in the case of this project was to MC. The contractor determines the amount and layout options that will be offered to customers;
- Request from the contractor to the designer for the development of plan options;
- Provision of plan and floor covering options to customers through a form that must be completed, along with the identification of owner and apartment. The declaration of the chosen options can be performed also by e-mail, letter or phone call directly to the customization section of the company;
- Final development of the project made compatible with other projects (structure, facilities, landscaping etc.);
- Construction and project delivery.

RESULTS AND DISCUSSIONS

First, the number of variants have been identified and their characteristics, according to Figure :

- Family Option: 3 suites, 1 cabinet, toilet and linen closet;
- Grand Family Option (Variant A): 4 suites, one with reversible bathroom;
- Petit Family Option (Variant B): 3 suites with expanded and toilet room.

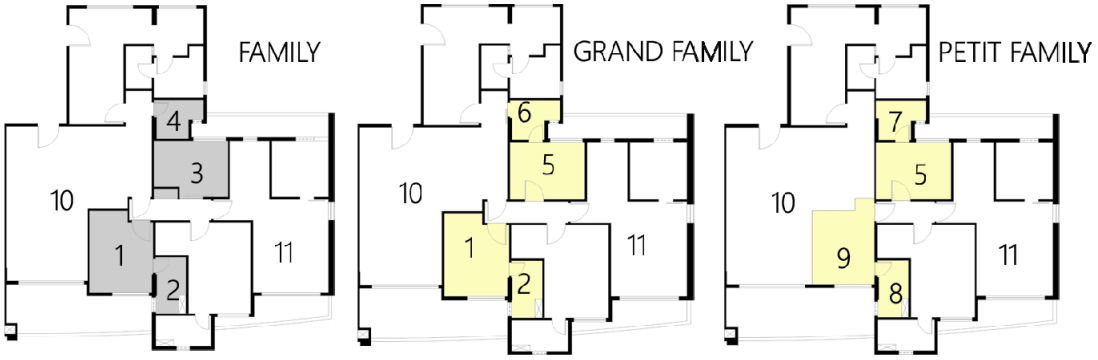

Figure 1: Numbers of variants.

This architecture includes mapping one-to-one from the functional elements relative to the frame to the physical components (Ulrich, 1995). To investigate this concept we analyzed each environment of each option plan. These environments were given the name of the module following the function that they develop and location in the plan, this survey identified 9 variants. Table 2:

Table 2: Options of layout

Module	Rooms
Module 01	bedroom 01
Module 02	bathroom 01
Module 03	cabinet and wardrobe
Module 04	toilet
Module 05	bedroom 02
Module 06	reversible bathroom
Module 07	bathroom 02
Module 08	toilet
Module 09	Extended room
Module 10	Platform 01: living room and dining, kitchen, service area, dependence.
Module 11	Platform 02: bedroom 03, master bedroom, closet e hall.

The modules of the same environment form a module of families, described in Table 3 below:

Table 3: Module of families

Type of family	Module
Family A	Modules 01 e 09
Family B	Modules 02 e 08
Family C	Modules 03 e 05
Family D	Modules 04, 06 e 07
Family E	Platform 10 e 11

CONCLUSIONS

To better utilize the strategy of MC we need to better understand the concept of PA and the use of modular architecture. This analysis concludes that in the set of families, there are modules that require change in plumbing and wiring design and masonry.

For Ulrich (1995), the solution would be to reduce interface contact surfaces, positions and sizes of the components. That is, the family of modules and interface should minimize the differences among the possible choices. We can see this most evidently between the petit family option and the other options. The interface module 9 for module 1 requires a decision of this option at a very early stage of the work, when the client should choose the plan before the completion of the structure. Postpone the decision of the customer to an earlier date of delivery of the product can generate greater satisfaction, as it corresponds the needs presented at the time of product delivery.

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