New product development for mass customization: a systematic review

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The incorporation of tools into New Product Development (NPD) process tends to contribute to the implementation of Mass Customization strategy in companies. Different knowledge areas – such as marketing, design and engineering – offer tools for different stages of product development. The specificity of those tools makes their selection and application to NPD process difficult. This paper aims at carrying out a literature review of applicable tools in respect to the NPD aimed at MC promotion. It also aims at identifying, according to its objective, its localization and application to NPD process. By means of a systematic review, 39 tools for NPD were identified. The results present bibliometrics on the tools, identify four tool clusters according to their contributions to product development, and also identify opportunities for research about the theme.

Keywords: new product development; mass customization; systematic review

1. Introduction

Mass Customization (MC) aims at delivering products that meet the individual needs of each customer at low cost (Pine, 1993). Literature and practice seen in companies show that the development of MC is primarily based on the use of flexible manufacturing system, information and communication technologies (Da Silveira, Borenstein, & Fogliatto, 2001; Fogliatto, Da Silveira, & Borenstein, 2012; Kotha, 1995; Piller, 2004) and on the insertion of tools applied to New Product Development (NDP) process, especially those that promote modularity (Gilmore & Pine, 1997; Jose & Tollenaere, 2005; Salvador, Forza, & Rungtusanatham, 2002).

There are basically three study areas to promote MC by means of NPD. The first area includes MC-oriented product development models, often denominated Design for Mass Customization (DFMC) (Jiao, Ma, & Tseng, 2003; Jiao & Tseng, 2004; Tseng & Jiao, 1996, 2001, Chapter 25). The main objective of DFMC is to widen the development view of one single product to a product family, incorporating the processes of sale, marketing, distributions and services (Jiao et al., 2003; Tseng & Jiao, 1996, 1998). The second area incorporates the NPD facilitators that contribute to the development of MC. Those studies aim at identifying issues that affect the performance of MC-oriented NDP, such as the effect of information technology on the integration of agents during the customization process (Asperen, 2008; Ming, Yan, Lu, Ma, & Song, 2002).
The third area incorporates tools and techniques developed for MC-oriented NPD. The improvement propositions in the product physical project are the most frequently found ones, with project methods of product families (Jianxin Jiao & Tseng, 1998; Williams, Allen, Rosen, & Mistree, 2007) and project methods of modular projects (Ericsson & Erixon, 1999; Stone, 1998) being the highlights. Propositions related to customer integration during NPD for MC are also identified, with the subject of product configurator or choice menu (Fettermann, Echeveste, & Schwengber ten Caten, 2012; Fogliatto & Da Silveira, 2008; Kaplan & Haenlein, 2006; Liechty, Ramaswamy, & Cohen, 2001) and innovation toolkits (Franke & Piller, 2004; Salvador, De Holan, & Piller, 2009; Von Hippel & Katz, 2002) being highlight.

Those tools are recommended to improve the NPD performance (Griffin, 1997; Krishnan & Ulrich, 2001), and are also recommended for several objectives and stages of NPD process (Nijssen & Frambach, 2000). Most of these tools, once associated to MC, are limited to the development of product architecture, especially regarding the subjects of product platform formation (Simpson, Siddique, & Jiao, 2006) and product modularization (Dahmus, Gonzalez-Zugasti, & Otto, 2001; Gershenson, Prasad, & Zhang, 2004). In addition to that, there is low adherence between these tools and company practice, much because of the difficulty in applying these propositions to the reality of NPD process in companies (Kahn, Barzak, Nicholas, Ledwith, & Perks, 2012). Among the reasons for the lack of application, the limited knowledge about available tools can be mentioned, and also the difficulty in finding such tools in the development process of a company. As a means to contribute to this subject, this paper aims at carrying out a literature review of applicable tools in respect to the NPD aimed at MC promotion and identifying, according to its objective, its localization and application to NPD.

The use of the tools identified in literature tends to contribute to achieving a high variety of product with low production cost, main MC objective (Slamanig, Schorling, & Stern, 2012). For this, the literature recommends that the product design must use concepts of product family design, modularity, commonality, flexible manufacturing, customer integration among others. (Fogliatto et al., 2012; Piller, 2004; Seepersad, Mistree, & Allen, 2005). The identified tools consist of an alternative to incorporate these concepts in product design for the MC. However, the use of these tools can also help in other types of product design that have the same goals.

The systematic review procedure (Kitchenham, 2004) was used as a means to find in the literature such tools to MC-oriented NPD. This paper also presents the research strategy, describing every stage of the study. The results are presented and assessed, so that, finally, opportunities for future research can be presented.

2. Research strategy

The development of evidence-based literature studies has been widely reported in surveys in general (Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007; Kitchenham et al., 2009; Magarey, 2001). For this, the use of systematic review of literature is a way for evaluating and interpreting all available research relevant to a particular area or phenomenon of interest (Kitchenham, 2004). The use of a systematic review is mentioned as a way to limit bias, provides a clear and replicable research process, and provides more reliable results upon which to make draw conclusions and decisions
The research method of systematic review used is based on the proposition developed by Kitchenham (2004), and it is widely used in literature (Afzal & Torkar, 2011; Alves, Niu, Alves, & Valença 2010; Brereton et al., 2007; Kitchenham et al., 2009). Its application follows six steps: (i) research issues, (ii) research process, (iii) criteria for inclusion and exclusion, (iv) assessment of study quality, (v) data collection and (iv) data analysis.

2.1. Research issues
The research issues leading this study are: (i) what are the NPD tools to promoting MC? and (ii) what is the association between the objectives of tools and activities of NPD? The deployment of such questions leads the literature review about MC-oriented NPD tools, as well as its application to the NPD process.

2.2. Research process
Data analyzed in this research are based on published articles, using a secondary source of data. Articles published in journals indexed in the Web of Science, Science Direct, and EBSCO databases were used as source of data. The search algorithm used the keywords ‘product development’ AND ‘mass customization’ OR ‘mass customisation’. This search is limited to titles, abstracts, and keywords, and there was no filtering regarding the publishing date. The procedure was carried out between 1st October 2012 and 10th October 2012, and 90 occurrences were found.

2.3. Criteria for inclusion and exclusion
First, five articles were excluded, for they were not related to the subject in case. With the 85 remaining articles, the objective was trying to identify which ones proposed tools applicable to NPD that could contribute to MC development. In this paper, a physical or intellectual instrument used in the execution of one or more activities is deemed as a NPD tool (Daychouw, 2007; Rozenfeld et al., 2006). A technique contributes to task execution (Mitcham, 1984), and is incorporated to the tool. In this paper, the techniques are classified as follows: (i) analytical techniques, which contribute to activity execution and (ii) computer technique, software-associated, which supports execution of proposed activities.

With this taken into account, 39 articles were identified, each of which offers a tool for NPD. The operation of each tool may suggest the use of one or more techniques. Each of these tools can still be recommended for performing one or more activities of the NPD process, with its objective being associated with this activity.

2.4. Assessment of study quality
The quality of the selected articles was indirectly assessed by the journals, since all occurrences have as source indexed journals with an evaluation system by means of referees.

2.5. Data collection
Every activity provided in a NPD process can be supported by one or more tools, as well as each of those tools may support one or more activities at different stages of the
NDP process. From the identification of tools and analysis of their application, it was possible to relate the proposed results with activities provided in a generic model of NDP process. The NPD model proposed by Ulrich and Eppinger (2000) was selected for that.

2.6. Data analysis

The data analysis is divided into two stages: bibliographic analysis and tool analysis. The bibliographic analysis presents the selected tools, descriptive analysis of the journals with the highest number of publications and home institutions of the authors. The tool analysis presents which activities of the referential NPD proposed by Ulrich and Eppinger (2000) are associated with the object of each tool. A matrix was developed as a result, in which \( i \) tools and \( j \) activities of NPD are related. After that, cluster analysis is proposed for the identification of tools that has similarities of application in NPD and that might be an alternative for the execution or support of the same activities of product development. This type of analysis aims at adding observations according to their characteristics, resulting in groups with internal homogeneity, and heterogeneity between groups (Gore, 2000, Chapter 11; Hair, Anderson, Tatham, & Black, 1995; Norušis, 2011). In this case, similar standards are investigated between the objective of the \( i \)th tool and the objective of the \( j \)th activity of NPD.

Among the methods of cluster analysis, the hierarchical method, as well as the Jaccard similarity measure were chosen (Milligan & Cooper, 1986) due to the binary characteristic of data and the exclusive interest in occurrences in which the \( i \) tool is associated with the \( j \) activity of NPD process. In order to better assess the arrangement, the cohesion between the occurrences is considered, as well as the separation between clusters, measured by means of the Silhouette coefficient (Norušis, 2011; Rousseuw, 1987). Every tool cluster identified is later presented, along with the cases for application and recommended techniques. The analyses proposed are carried out with Excel® and SPSS v.17® software.

3. Results

3.1. Bibliographic analysis

The list with the 39 articles containing propositions of tools for NDP process aimed at MC is shown in Table 1. The identification (Id) of each article is then used to identify the study.

The 39 articles selected were published in 20 different journals. Among the journals with the highest number of occurrences in the subject are International Journal of Production Research, Concurrent Engineering-Research and Applications, and Computers in Industry and with 18 occurrences, which correspond to 46% of the articles containing proposals of MC-oriented NPD tools. Concerning the time period of the publications, the first publication about the subject is from 1998 (Jiao, Tseng, Duffy, & Lin, 1998). Since then, the amount of publications about the subject presents an upward trend.

The home institutions of each author were identified among the 39 publications under analysis. In total, 123 authors were identified, being affiliated with 46 different institutions in 16 different countries. Among the institutions with affiliated authors, it is seen that only four of these are not universities, which indicate low adherence of researchers with publications in companies. Regarding the home institutions of the authors, it is seen that the greatest part of the authors are affiliated with Chinese or
| Id | Title                                                                 | Authors and year          |
|----|----------------------------------------------------------------------|----------------------------|
| 1  | A methodology of developing product family architecture for mass customization | Jiao and Tseng (1999)     |
| 2  | Product family modeling for mass customization                        | Jiao et al. (1998)        |
| 3  | Architecture of product family: fundamentals and methodology          | Du et al. (2001)          |
| 4  | Functional interdependence and product similarity based on customer needs | McAdams et al. (1999)     |
| 5  | A fuzzy analytic hierarchy process approach in modular product design  | Lee et al. (2001)         |
| 6  | Applications of the web-based collaborative visualization in distributed product development | Chu et al. (2006)        |
| 7  | Product development cost estimation in mass customization             | Tu et al. (2007)          |
| 8  | Operational tactics and tenets of a new manufacturing paradigm ‘instant customerisation’ | Tang et al. (2005)       |
| 9  | A design decision-making support model for customized product color combination | Ma et al. (2007)         |
| 10 | Analytical affective design with ambient intelligence for mass customization and personalization | Jiao, Xu, et al. (2007)  |
| 11 | A reconfigurable platform in support of one-of-a-kind product development | Xie et al. (2005)        |
| 12 | Service Architecture and Modularity                                   | Voss and Hsuan (2009)     |
| 13 | A web-based fuzzy mass customization system                           | Chen et al. (2001)        |
| 14 | Supporting ‘design for re-use’ with modular design                    | Meehan et al. (2007)      |
| 15 | A decision support system for rapid one-of-a-kind product development | Xie (2006)                |
| 16 | Product platform identification and development for mass customization | Huang et al. (2003)       |
| 17 | Virtual customer integration in new product development in industrial markets: the QLL framework | Hemetsberger and Godula (2007) |
| 18 | Evaluation of product performance in product family design re-use    | Xu et al. (2007)          |
| 19 | A framework of product styling platform approach: styling as intangible modules | Fung et al. (2004)       |
| 20 | Integrating rough set clustering and grey model to analyze dynamic customer requirements | Chen and Wang (2008)    |
| 21 | A dynamic workflow framework for mass customization using web service and autonomous agent techniques | Karpowitz et al. (2008) |
| 22 | Using product family evaluation graphs in product family design       | Ye et al. (2009)          |
| 23 | Manufacturing network for rapid tool/die making                       | Tu and Kam (2006)         |
| 24 | Internet-based framework to support integration of customer in the design of customizable products | Ninan and Siddique (2006) |
| 25 | A generic and extensible information infrastructure framework for mass-customizing platform products | Huang et al. (2007)      |
| 26 | ppXML: A generic and extensible language for lifecycle modelling of platform products | Huang et al. (2008)    |
| 27 | On Modular Products Development                                       | Kong et al. (2009)        |
| 28 | Integrated Vehicle Configuration System-Connecting the domains of mass customization | Helo et al. (2010)       |
| 29 | Modularity analysis and commonality design: a framework for the top-down platform and product family design | Liu et al. (2010)       |
North-American institutions, which correspond to almost 60% of the home institutions of all authors. In Asia, it is also possible to see institutions from Singapore and Taiwan. There is a smaller amount of articles in Europe, and authors affiliated with several institutions (Figure 1).

The concentration of institutions in China is even more prominent in Hong Kong, which houses institutions of 30 authors, meaning that 24.4% of the authors were affiliated with institutions from Hong Kong and that the city is a research center about the subject. Among the Hong Kong institutions, the University of Hong Kong and the Hong Kong University of Science & Technology stand out, with 17 and 8 authors, respectively. Other institutions that also have a high number of publications are the Shanghai Jiao Tong University, from China, with seven authors, and the Nanyang Technological University and the National University of Singapore, both from Singapore, with seven and six authors, respectively.

| Id | Title                                                                 | Authors and year                          |
|----|----------------------------------------------------------------------|-------------------------------------------|
| 30 | An integrated fuzzy logic approach to customer-oriented product design | Gologlu and Mizrak (2011)                 |
| 31 | Fuzzy Topsis Decision Method for Configuration Management           | Chang and Tseng (2008)                    |
| 32 | Web Service-oriented Electronic Catalogs for Product Customization   | Ma et al. (2008)                          |
| 33 | Ontology-Based Multiplatform Identification Method                   | Li et al. (2010)                          |
| 34 | Developing and Assessing Commonality Metrics for Product Families: a process-based cost-modeling approach | Johnson and Kirchain (2010)               |
| 35 | The importance of product development cycle time and cost in the development of product families | Johnson and Kirchain (2011)               |
| 36 | An Approach to Constraint-Based and Mass-Customizable Product Design | Nordin et al. (2011)                      |
| 37 | Matching product architecture with supply chain design               | Nepal et al. (2012)                       |
| 38 | Two-stage product platform development for mass customisation        | Qu et al. (2011)                          |
| 39 | A helical model for managing innovative product and service initiatives in volatile commercial environments | Deakins and Dillon (2012)                |

Figure 1. Location of the home institutions of the authors with selected articles.
3.2. **Analysis of tools**

After the analysis of each tool, it was possible to identify which NPD activities have their objectives associated with what is proposed by each tool. For this, the referential NPD process proposed by Ulrich and Eppinger (2000) was used, subdivided in 49 activities. The association between i tools and j activities is presented in partial form in Figure 2, where ‘1’ represents when certain ith tool contributes or supports the execution of the jth activity of the NPD. The database is presented in its complete form in Appendix 1.

With this matrix, the i tools are grouped according to their similarity of application to the j activities of the NPD process. The Silhouette coefficient (Si) (Rousseuw, 1987) indicates that the best arrangement is achieved with four clusters (Si = 0.575), according to what is seen in the Dendogram (Figure 3).

The four tool clusters were denominated according to their activities in the NPD process which they associate to: (i) product family project, with 18 occurrences; (ii) customer integration to NPD, with 10 occurrences; (iii) manufacturing project, with three occurrences; and (iv) project planning, with eight occurrences. Each group has tools associated to one or more activities in different stages of the NPD process. The identification of such groups is shown in Figure 4, along with the location of each tool analyzed and its contribution to the stage of the NPD process.

![Figure 2. Partial database.](image-url)
The orientation of the tools analyzed is seen to be in most cases aimed at the initial steps of the NPD process, corresponding to 78.2% of the sample of articles. Issues about the influence of the product project on the manufacturing system, production sequencing, definition of production batches, reliability of customized products, and
quality assurance of those are not approached among the tools analyzed. Tools aiming at product launching, usage tests, and market tests were also not found.

3.2.1. Product family project

The first group of tools is the most frequent one in the literature, with 18 articles, which corresponds to 42.2% of the occurrences in the publications analyzed. These tools are more focused on the execution of the activities found primarily in the Planning, Concept Development, and System-Level Design stages. The results of these activities are primarily related to the planning of the product family and the physical concept of the product, including modular architecture, product platform, and modules. This cluster was denominated product family project for this reason.

In the Planning stage, the activity of assessing and prioritizing projects – and, more precisely, the sub-activity of planning the product platform – is frequently the initial activity of the tools within this group, especially those developed for the re-project or optimization of the product or portfolio (Du, Jiao, & Tseng, 2001; Huang, Bin, & Halevi, 2003; Meehan, Duffy, & Whitfield, 2007; Qu, Bin, Huang, & Yang, 2011). There are also tools that initiate the product family project, with the analysis of customer needs. With this characteristic, Fung, Chong, and Wang (2004) propose an analysis of tangible and intangible needs of customers about the product, directing the formation of the product platform and modules. The proposals by Kong et al. (2009), Xu, Ong, and Nee (2007) and Liu, Wong, and Lee (2010) initiate the project of the platform considering the analysis of customer needs, its clustering, and association to product subsystems.

In the Concept Development stage (activities about developing product concepts), the activities that have the greatest support by the tools analyzed are most frequently the sub-activities of functional mapping of the system and managing of the selection process. For the functional mapping of products, it is more frequent for tools to recommend the use of the heuristics developed by Stone (1998), which subdivides the systems and analyzes the energy flows of energy, material, or signals between the subsystems (Stone, Wood, & Crawford, 2000).

In the System-Level Design stage, the activities of developing the product scheme, grouping elements in subsystems, and the planning of product family and platform are the most supported ones with the sub-activities of plan of differentiation and commonality among the derived products being the highlights. The use of product modular architecture and the organization of subsystems into modules consist in an important strategy to meet MC (Ro, Liker, & Fixson, 2007; Robertson & Ulrich, 1998; Salvador et al.,...
Therefore, these activities are the ones most frequently supported by the tools analyzed. The analysis of the trade-off between module variety for the meeting of requirements of the market segments and the element commonality for the maintenance of the scale economies is also approached in the tools. Nevertheless, this topic is frequently treated superficially in the proposals analyzed. The proposals by Voss and Hsuan (2009), Johnson and Kirchain (2010), and Liu et al. (2010) contribute to this objective. The other stages of NPD proposed by Ulrich and Eppinger (2000) are not supported by the tools in this cluster.

Among the tools of that group, there are those that present the method of support to customization based on the project of modular architecture products, denominated as PFA (Product Family Architecture) (Du et al., 2001; Jiao & Tseng, 1999; Jiao et al., 1998). This method is structured in the analysis on three project dimensions: functional, technical, and physical. In the functional dimension, one can find the issues associated with the functional requirements of the product and its inter-relations, and also how these relate to each market segment. The technical dimension refers to the technology applied to the product and its conversion into subsystems aiming at developing a modular architecture with a product platform and modules aiming at meeting customer needs. The physical dimension is related to the product materialization, including restrictions of manufacture and assembly for the maintenance of scale economy. In order to have project problems solved, several techniques are recommended, such as cluster analysis to identify market segments, hierarchical analysis (AHP) (Saaty, 1991) for

| Application | Sector |
|-------------|--------|
| Power supply (1;2;3), Automotive dashboard (cockpit) (34), Automotive air conditioning system (37), Electric motor (38) | Intermediate goods |
| Iced tea machines (4), Coffeemaker (4), Fruit peeling machine (4), Pager (5), Mobile Phone (18), Personal computers (19), Wireless screwdriver (29), Water cooler (33) | Consumer goods |
| Sea travel agency (12), Bank (12) | Services |

| Analytical Techniques | Articles |
|-----------------------|---------|
| Clustering algorithm | 1 |
| Algorithm for configuration | 37 |
| Product Tree analysis | 1;2;3;16;38 |
| Cluster Analysis, Fuzzy Cluster Analysis | 1;14;27;29;33 |
| Life Cycle Assessment – LCA | 27 |
| Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) | 1;5 |
| Financial Assessment | 1;27 |
| Conjoint Analysis | 27 |
| Tools and Methods for Modular Architecture (Method of Module Heuristics (Stone et al., 2000); MFD (Ericsson and Erixon, 2000); DSM (Steward, 1981); Pimmler e Eppinger (1994)) | 1;4;14;18;27;29;33 |
| DFx (Design for Assembly, Design for Manufacturing, Design for Service, Design for Reuse, Design for Postponement, Design for Variety) | 1;27 |
| Bubble chart | 27;29 |
| Pareto chart | 1 |
| Group technology (GT) | 32 |
| Commonality indicator | 12,29,34 |
| Correlation matrix | 18 |
| Real options | 27 |
| Cluster optimization | 14;16;18;29;38 |
| Market research (customers, survey) | 1 |
| Operational research (linear programming) | 37 |
| QFD (Quality Function Deployment) | 27;33 |

| Computer Techniques | Article |
|---------------------|---------|
| CAD systems | 32 |
| PDM and PLM systems (Product Data Management and Product Life Cycle Management) | 32 |
| Programming languages (Java Programming Language) | 32 |
| Communications protocol (Simple Object Access Protocol (SOAP), Standard Component Library (SCL)) | 32 |

Figure 5. Application and recommended tools and techniques in the product platform project.
hierarchization of attributes in each market segment, product deployment into subsystems, and its analysis as matrices (Pimmler & Eppinger, 1994), and clustering algorithms for module formation (Kusiak & Chow, 1987).

Among the tools proposed for the product family project, most of them have their application illustrated in cases. Such cases illustrate the application of the tools in a variety of products of different technological complexity, such as a coffeemaker and its development (McAdams, Stone, & Wood, 1999) and an air conditioning system (Nepal, Monplaisir, & Famuyiwa, 2012). There is also a concentration of applications in the development of products aimed at intermediate goods, which are part of other products, and consumer goods, aimed at the end user (Figure 5).

Among the analytical techniques recommended by the tools examined, the techniques for clustering of product subsystems (such as the proposals of modular architecture) are the indication most frequently seen. With that objective, there is the heuristics proposed by Stone (1998) and the Design Structure Matrix (Steward, 1981) and its variations, such as Pimmler and Eppinger (1994), and Eppinger, Whitney, Smith, and Gebala (1994), both based on processes of deployment of the project into minimum parts inter-related among themselves (Alexander, 1964). After using matrices to analyze the relation between subsystems, these are normally clustered by means of cluster analysis techniques, with the Euclidean distance measure being normally used to identify product modules and platforms. After that identification, some tools recommend the optimization of the cluster, in order to improve the product structure identified, by means of genetic algorithms (Meehan et al., 2007; Qu et al., 2011) or by including other issues, such as aspects of the supply chain (Nepal et al., 2012) (Figure 5).

Computer techniques are associated with tools that contain information systems to help the product family project. Those proposals are the result of the need for dynamism in the customization process, and also the need for integrating several agents to such process. Within that topic, Ma, Jiao, and Deng (2008) propose a system integrating Computer Aided Design (CAD), Product Data Management (PDM) and Product Lifecycle Management systems for creation, maintenance, and operationalization of a library of components in the web for the promotion the commonality of part numbers among the company’s product portfolio. Tu and Kam (2006) present a proposal of CAD system integration with other manufacturing systems, such as machines with Computer Numerical Control, and systems of Computer-Aided Process Planning, aiming at increasing the dynamism of the customization process of product (Figure 5).

3.2.2. Customer integration in NPD

It is the second most frequent group in the sample that was used, comprising 10 tools. The proposals are focused on activities included in the Concept Development and System Project stage of the NPD referential model proposed by Ulrich and Eppinger (2000). In the Concept Development stage, the most frequent activities supported by the tools are the identification of customer needs and the definition of the final set of specifications. Because the MC strategy predicts customer participation in the product project (Da Silveira et al., 2001; Fettermann, Echeveste, & Martins, 2012; Franke & Piller, 2003; Piller, 2004), the tools included in this clustering contribute to help customers to realize product customization, identifying their needs, and translating these into product specifications. Afterwards, in the system project stage, the most supported activity by methods and tools is identifying associated services. That characteristic occurs because of the fact that many methods and tools proposed, in addition to contribute to the
product setting, make several associated services available to customers, which increases the quantity of options presented to them.

Most tools of this group are characterized by providing mechanisms to help the customer to customize the product (Chang & Tseng, 2008; Chen, Wang, & Wong, 2001; Gologlu & Mizrak, 2011; Jiao, Xu, et al., 2007; Ma, Chen, & Wu, 2007; Ninan & Siddique, 2006; Nordin, Hopf, Motte, Bjarnemo, & Eckhardt, 2011). With that specific objective, Ma et al. (2007) propose a mechanism to reduce the complexity of product customization process by customers. Using factor analysis and Fuzzy AHP techniques, abstract requirements by customers (such as modern, elegant or young) are translated into technical specifications of product. The tool use is exemplified in the customization process of a sofa. The result leads the customization alternatives to the profile of the customer, reducing the process complexity.

Still following this line of ideas, Chen et al. (2001) presented a similar proposal. By means of a system via web with the use of Virtual Reality Modeling Language, customer demands (such as small and wide) are processed and translated into product specifications. Using fuzzy logic applied to the customization of chalices, customer demands are processed and result in specifications in a CAD system. Gologlu and Mizrak (2011) propose an online product configurator that uses fuzzy logic to analyze customer demands and translate them into product specifications, resulting in a CAD design of the customized product. Ninan and Siddique (2006) also propose and online product configurator, however, in addition to resulting in CAD designs, it also optimize the structure of the customized product by means of Finite Element Analysis (FEA). Both tools are exemplified in the customization of a bicycle. Jiao, Xu, et al. (2007) propose a tool to facilitate the customization process of a product by the customer. That proposal is illustrated in the customization of a truck, in which the customer uses the product virtually by means of Virtual Reality and Augmented Reality techniques, having their demands translated into product specifications and remodeled with the conjoint analysis technique, and also optimized by means of genetic algorithm. Chang and Tseng (2008) propose a tool for a customized product project in which customer demands are analyzed by means of fuzzy QFD and selected using the TOPSIS algorithm. Nordin et al. (2011) propose the use of logics for the customization of table surfaces. With dimensional information about the product at hand, the Voronoi Diagram is used for the customization of the product surface, and by means of operational research, a proposal is made concerning the best arrangement in relation to cost.

The other tools in this group have less specific foci. Helo, Xu, Kyllönen, and Jiao (2010) propose a structure to integrate the other systems used by the company, such as Bill of Materials (BOM) organization, production, manufacturing logistics, and distribution. Hemetsberger and Godula (2007) developed a support tool to decisions about alternatives to integrate customers to NPD for product customization in reason of knowledge transference capability of each alternative. Chu, Cheng, and Wu (2006) propose a support system to information flow which contributes to the definition of the strategy of the supply chain. By means of a tridimensional product configurator, both the company departments involved in the development and the suppliers can access the catalog of components/products based on a visualization system via web. By means of integrating information from CATIA® systems, PDM, and the BOM of the products, it is possible to access the information and its visualization from the ones involved in the project.

Most tools in this group have an example of application (Figure 6). Among these cases, higher application frequency is seen in the development of consumer goods, mainly because of greater contact with customers.
Regarding the techniques recommended by the tools of this group, there is no concentration in one type of specific technique (Figure 6). Among analytic techniques, the use of proposals to collect and analyze market data – such as market research, data mining, and conjoint analysis – is recommended more frequently (Helo et al., 2010; Jiao, Xu, et al., 2007). Among computer techniques, the highlights are those used to enable customer participation in the project, from projects by means of CAD systems (Chu et al., 2006; Gologlu & Mizrak, 2011; Ninan & Siddique, 2006), their analysis by means of Visualization Systems (Chen et al., 2001; Jiao, Xu, et al., 2007; Ninan & Siddique, 2006), and the delivery of such mechanism through internet, enabled by languages and protocols applied to web (Chu et al., 2006; Ninan & Siddique, 2006).

### 3.2.3. Manufacturing project

The third tool clustering is also little frequent in the literature and has only three proposals aimed at the activities included in the detailed project stage of the NPD referential model by Ulrich and Eppinger (2000). Generically speaking, the common characteristic of those tools is contributing to support definitions related to the manufacturing project of customized products.

Tu, Xie, and Fung (2007) present a proposal to estimate the manufacturing cost of customized products, and also a routine to optimize them during the customization process. Starting at the product family structure, it incorporates variables related to manufacturing processes, logistics and suppliers for the product options. After such analysis,
two cost estimates are made available: one from a derivative product, when some new component or subsystem is developed at the product, and another from a standardized product, when the configuration is carried out only with standardized components or subsystems. Xie, Xu, and Tu (2005) propose a system to optimize the production of customized products. From geometric information found in the CAD about the product and information about manufacture and resources of the company, a simulation of the production is performed in potential environments of the factory, which indicates the most economic route for the product. Xie (2006) develops an information system via web to support the project of customized products. It consists in several modules and tools aimed at helping decision-making regarding options of manufacture, assembly and costs, besides project management.

The cases in which those tools were applied do not have direct connection with the market (Figure 7). Two tools are applied to cases in one company located in Christchurch, New Zealand (Xie, 2006; Xie et al., 2005). Just like the proposal by Tu et al. (2007), i.e. one applied to the manufacture of a component composed by a folded and machined steel sheet, the cases illustrated in this group have as central objective the optimization of the manufacturing process of customized products, reducing production costs resulting from greater variety of products.

The support techniques to the tools aimed at the manufacturing project focus on the integration between systems (Xie, 2006; Xie et al., 2005), based on intranet-accessible languages or even via web. In the proposals under analysis, there was also some orientation towards the integration between pieces of software (used in the project and manufacturing ones) for the definitions related to the customized projects (Figure 7).

3.2.4. Project planning

The eight tools in this cluster are characterized by their support to activities in the planning stage in the NPD referential model proposed by Ulrich and Eppinger (2000). In this stage, the proposals in this cluster aim at identifying or supporting business opportunities; for that reason, they were associated with the opportunity-identification activity. Furthermore, there are also tools that contribute to allocate resources and project schedule, associated with the project planning activity.

Tang, Chen, and Ji (2005) present a structure in the shape of a decision tree to support decision-making, and identify prerequisites and facilitators for the development of a fast customization structure in a manufacturing company. Deakins and Dillon (2012) develop a proposal for the assessment of virtual business opportunities for internet-based
companies. Ye et al. (2009) develop a tool to be applied in benchmarking, comparing the performance of the product family in relation to variety and commonality of components. The results of that analysis allow identifying opportunities by comparing the performance of competitors in different market segments. Chen and Wang (2008) develop a proposal to group and analyze the history of purchases, customer requirements and product functional requirements, and then incorporate these in a forecast of assessment of such requirements by the market.

Karpowitz, Cox, Humpherys, and Warnick (2008) develop a system aiming at planning and organizing the activity flow for the execution of the planning project. Using Java programming, the system makes easier the identification of necessary resources for the development, the execution of the project plan, and the integration with the other systems used. Huang et al. (2008) propose a project managing system aimed at the support of the product platform project. Using ppXML language, their proposal is about a system for web that incorporates several tools for the platform development, such as portfolio management, derivative products, and product tree, as a way to support the project team to plan and manage the execution of the product family project. Huang, Li, Lau, and Chen (2007) propose an information portal for the support to information coordination and flow for the product platform project. Johnson and Kirchain (2011) develop a structure to estimate the costs of the product family project. By means of a financial assessment composed by four costs related to the effort employed in the project, the equipment used in the development, the software used, and project supervision, it is possible to identify the quota of development cost of each variable derived from the product family. The tools in this group have their propositions applied to consumer goods and intermediate goods (Figure 8).

The techniques used by the tools in this cluster are reduced, being focused on the analysis of the resources needed to develop the product. Karpowitz et al. (2008) and Huang et al. (2008) develop systems for project management, and the techniques suggested are associated to the programming language used in the development of the system proposed. The proposal by Johnson and Kirchain (2011) uses financial analysis techniques to attribute the costs related to the development of the product family. As a

| Application                  | Sector            |
|------------------------------|-------------------|
| Crane (25)                   | Capital goods     |
| Electric bicycle (20), Hand tools family (De Walt, Black & Decker, Skil, Delta) (22) | Consumer goods |
| Steel component (21), Reducer (26), Cockpit (35), Automobile chassis (35) | Intermediate goods |

| Analytical Techniques | Articles |
|-----------------------|----------|
| Financial analysis    | 35       |
| Cluster analysis      | 20       |
| Consistency analysis  | 20       |
| Multi-criteria decision analysis | 22       |
| Analytic Hierarchy Process (AHP) | 20       |
| Decision support structure (framework) | 8        |
| Variety indicator     | 22       |
| Commonality indicator | 22       |
| Demand forecasting    | 20       |

| Computer Techniques | Article |
|---------------------|---------|
| Programming languages (Platform Product eXtensible Markup Language-ppXML, eXtensible Markup Language-XML, Java Programming Language) | 21; 25;26 |
| Communications protocol (Simple Object Access Protocol – SOAP) | 25 |

Figure 8. Application and recommended tools and techniques in the project planning.
way of enabling those systems to project planning, there is a recommendation for XML (Huang et al., 2008, 2007) and Java (Karpowitz et al., 2008) programming languages.

3.3. Research directions

After the bibliographic analysis and tool analysis, it was possible to identify some research gaps that were not satisfactorily met by the works analyzed.

3.3.1. Tools related to market segmentation

The MC strategy is mentioned as an alternative before the trend of increasing of the diversity of customer needs (Hart, 1995; Kotha, 1995; Pine, 1993). The authors defend product personalization, dealing with individual customer needs (Kumar, 2007; Tseng, Jiao, & Wang, 2010). Given the difficulty in operationalizing the production of individual items in certain industrial sectors, the use of tools for market research, data analysis, identification of market segments, and trend forecasting of valuation requirements associated with customized products is presented as a research opportunity. Although there are publications associated with the subject, those do not yet address the problem from the standpoint of MC, not showing a direct relationship between the requirements of the market segments and their translation into the construction of the platform and modules of customized products. Studies associating tools with referential NPD tend to have their applicability facilitated, as they approach the development process, increasing its adherence to the reality of companies.

3.3.2. Development of MC-oriented NPD process

Although the MC strategy is often applied by manufacturers of consumer goods and product development methods available in the literature are suitable for this type of product (Clark & Fujimoto, 1991; Pahl & Beitz, 1996; Roozenburg & Eekels, 1995; Rozenfeld et al., 2006; Ulrich & Eppinger, 2000), there is no adherence between these methods and the MC strategy. In MC, the product development is often treated in a context of product family (Meyer & Lehnerd, 1997) with a greater focus on the development of modular product architecture and commonality of components (Gilmore & Pine, 1997; Jose & Tollenaere, 2005) plus efficient customer integration during product development (Duray, Ward, Mulligan, & Berry, 2000; Piller, 2004). Because of these characteristics, there is a need to adapt the product development models for their effective incorporation.

3.3.3. Organization of tools for the NPD process and systematization of the selection process

NPD tools able to promote the MC strategy are frequent in the literature. In this paper, among the 80 publications selected, 39 had propositions of tools. In addition to the publications analyzed, some authors propose gathering some of these tools that are scattered in the literature. Dahmus et al. (2001) identify alternatives for the development of modular architecture of products. In a literature review, Simpson (2004) identifies and classifies 34 tools for the optimization of the product family project. Several authors present reviews about tools for the development of modular architecture and product platform (Gershenson et al., 2004; Jiao, Simpson, & Siddique, 2007; Jose & Tollenaere, 2005;
Simpson et al., (2006). In publications more focused on MC, like Fogliatto and Da Silveira (2011), there are also tools applicable to NPD, like Ben-Arieh (2011, Chapter 6) and Chowdhurry and Siddique (2011, Chapter 7), who also focus on project and optimization of the product platform.

Although those studies identify several alternatives for the orientation of the NPD process to the benefits of MC, they are still limited to the project of platform and product family. Another need still resides in the selection of which tools should be applied to the NPD process of companies. There are different levels of MC adopted by companies, which tend to follow the logic of postponing production. At a higher level, it is possible to incorporate customer participation since product conception, in which customers modify the project structure, creating a new product for the company and the customer. At the other extreme, the company produces standardized products and the customer is integrated in the final process, selecting alternatives of distribution of the product (Yang & Burns, 2003; Yang, Burns, & Backhouse, 2004). According to the customization level adopted by the company, the NDP process should be directed to the specific stages of product development. Companies that operate at higher levels of customization interact more with customers during development, therefore they need more tools for this purpose. In another context – more standardized products with lower levels of customization – greater guidance is expected to optimize product and process, with the adoption of tools aiming at these purposes. Because of these differences, the development of a proposal for the selection of MC-oriented NPD tools based on customization levels may contribute to the greater adoption of such tools by the companies.

4. Conclusion
The objective of this paper was to carry out a literature review about tools applicable to NPD to promoting MC and identifying, according to their objective, their application in the NPD process. A systematic review in the literature found 39 tools and 67 different techniques recommended to MC promotion by means of NPD. Those tools, available in the literature, have broad application in development projects, and their application is recommended from initial activities of the until activities related to the commercialization of the product. This paper contributes to identify the characteristics of the tools and group them by similarity of application in NPD. For future research, we recommend the use of more search terms to complement the results.

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## Appendix 1.

| Id. | Planning | Concept Development | System-Level Design | Detail Design | Testing and Refinement | Production Ramp-up |
|-----|----------|---------------------|---------------------|--------------|-----------------------|-------------------|
| 1   | 0        | 1                   | 2                   | 3            | 4                     | 5                 |
| 2   | 0        | 0                   | 1                   | 2            | 3                     | 4                 |
| 3   | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 4   | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 5   | 0        | 0                   | 0                   | 0            | 0                     | 0                 |
| 6   | 0        | 1                   | 1                   | 2            | 3                     | 4                 |
| 7   | 0        | 0                   | 0                   | 1            | 2                     | 3                 |
| 8   | 0        | 1                   | 1                   | 2            | 3                     | 4                 |
| 9   | 0        | 0                   | 0                   | 0            | 0                     | 0                 |
| 10  | 0        | 0                   | 0                   | 1            | 2                     | 3                 |
| 11  | 0        | 0                   | 0                   | 1            | 2                     | 3                 |
| 12  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 13  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 14  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 15  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 16  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 17  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 18  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 19  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 20  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 21  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
| 22  | 0        | 1                   | 0                   | 1            | 2                     | 3                 |
