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Conceptual model for the design of product systems

Modelo conceptual para el diseño de sistemas de productos

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ABSTRACT

Based on the concepts of personalization, differentiation and variability, product systems are characterized and the conditions for their design are explored. In the analysis of literature,17 variables related to the design of product systems were identified, and used to develop a conceptual model. In order to validate this finding, a survey was applied to 57 experts in the field of design. By means of a factor analysis, variables are reduced and the underlying conceptual relationships are identified. As a result of the validation, three factors are identified: structure, coherence and order, which contain the variables that determine the attributes of the product systems. These findings support the conclusion that the origin of the design process of these systems is based on the analysis of consumers and the multiple uses given and experiences obtained from these products. Study boundaries are established and future research possibilities are outlined.

Keywords: Product systems, differentiation, variability, systemic design, customization.

RESUMEN

A partir del estudio de los conceptos de personalización, diferenciación y variabilidad, se caracterizaron a los sistemas de productos y se exploran las condiciones requeridas para su diseño. En el análisis de la literatura se identificaron 17 variables relacionadas con el diseño de estos sistemas y se utilizaron para elaborar un modelo conceptual. Para validar este hallazgo se aplicó una encuesta a 57 expertos en el área del diseño. Mediante el análisis factorial se reducen las variables y se identifican las relaciones conceptuales subyacentes. Como resultado de la validación, se identifican tres factores: estructura, coherencia y orden, los cuales contienen las variables que determinan los atributos de los sistemas de productos. Los hallazgos permiten afirmar que el origen de proceso de diseño de estos sistemas se basa en el análisis de los consumidores y los múltiples usos y experiencias que estos realizan con los productos. Se establecen los límites del estudio y se delinean futuras investigaciones.

Palabras clave: Sistemas de productos, diferenciación, variabilidad, diseño sistémico, personalización.

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Introduction

Globalization and the rise of ICTs have propelled demographic, technological and social transformations that, from industrial design, turn into changes in consumption patterns and user interaction with products, forcing the rupture of the paradigm of mass production and the logic of the economy of scale. Martins, Oliveira, and Relvas (2005) citing Alves and Braga (2001), state that massification of information and communication technologies has boosted standardization of products, services and consumer behaviors, where "social dynamics, trends and commercial applications are increasingly mutable" (p. 3); leading to an increase in the frequency of product launches, and multiplying the alternatives of products, which complicates the decision-making of consumers. In this sense, AlGeddawy and ElMaraghy (2011) state that causes of proliferation in the variety of products is found mainly due to the diversity in the requirements of consumers, different regional needs, different market segments, rapid technological changes and price discrimination, which prevents competition for low prices. In addition, the explosion of the offer of raw materials and means of production, and the specialization in management techniques are also relevant, resulting in a hyper-product offering in the market.

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Due to the high flow of information, markets are nowadays homogenized in "real time", as consumers will choose the product that gives them greater perceived value, beyond the technical specifications. In this regard, Sánchez (1997) proposes to interpret the product as an open system, focused structurally toward the context, mainly because the systems approach can address increasing complexity through modeling of interrelationships among consumers, products, and competitors in the market. Based on the aforementioned perspective, this study adopts the concept of "product systems" to refer to those groups of products that are developed in an articulated manner by a company, which form its portfolio and are part of its business strategy, regardless of the actions, means and places required to manufacture them (Cardozo *et al.*, 2014)

Davis (1987) was the first to argue that mass customization is developed when it reaches a large number of customers (such as those in markets of industrial economy), while these customers are individually served (as in markets of pre-industrial economies). Expanding these concepts, Dey (2010) establishes that mass customization denotes the ability to provide personalized products and services at a price and speed similar to those done under the standardization model, even when a high demand exists. For Braha and Maimon (1998) the need for companies of a wider variety of products and reduce development time, increases the complexity of the design process, manufacturing capabilities, and marketing. Mass customization focuses on the incorporation of strategies, techniques and actions for the development of the variety and customization of products, achieving development cycles shorter and more flexibility in products, emphasizing differentiation through design, within a scene of great fragmentation of demand and great heterogeneity in niche markets.

Differentiation

In today's market consumers are involved in a growing range of products, services and brands, where the technical differences between the products are declining, and technology is no longer a selection criterion for users. For Nam (2011), citing Ireland (1987), differentiation provides a competitive advantage unrelated to the price. Johansson (2010) argues that heterogeneity in consumer preferences allows companies to differentiate their products, because customers perceive subjectively the variations from one product to another (although from an objective point of view, there are very few differences); being the brand, design, usability, and the generation of emotions and sensations the most important attributes for product differentiation. Taking this behavior into account, the technology and price are becoming less important for customers. Following this approach, Nam (2011), citing Crimp (1990), states that the 'image' that the consumer has of the product affects their perception of product attributes. In this regard, Agard (2002) argues that the consumer is the creator of the variety, because of the diversity of uses that they give to the products. Therefore, the flexibility and adaptation processes are important qualities for companies. Although it is not possible to predict all possible uses that consumers give to the products, it is possible to define qualities and flexible features of the products that can be adapted by users. To achieve this, it is necessary to develop specific design methods focused on variability, to develop the ability of companies and manage this activity as a strategic process.

Variability

It was previously discussed how design focused on personalization generates increased complexity by including variability in product design. In literature, the approach of "product family" is presented as one of the best solutions to address this difficulty. Ulrich and Tung (1991) describe a product family as a group of products built from a group of much smaller components. Zhao *et al*. (2004) establish the link between consumers and the approach of "family" when they argue that a family of products is a collection of product variants that have the same functions but with different combinations of attribute levels. From the perspective of product systems, implementation of product families takes the form of derivative products based on platforms. Meyer and Lehnerd (1997) describe a platform as a group of common components, modules or parts from which a flow of derived products can be obtained. Chai *et al*. (2012) identified three key elements for the competitiveness of product platforms: extensibility of platform-based products, reuse of subsystems, and the compatibility of the interfaces of the subsystems.

Conceptual approach for the design of product systems using a systemic approach

Tseng and Jiao (1998) suggest going beyond typical design processes that focus on the design of a single type of product and which do not incorporate design strategies for product groups; and in turn propose to incorporate systemic criteria in design processes. This aims to focus design towards consumers and to enhance the experience of use and perceived value of products. This could also help manage the increasing complexity and amount of information during the development process of products.

As a method, modelization is used, from an internal perspective, to identify the features and variables that the system requires and those interrelationships between elements that compose them. From an external perspective, it is used to determine the interactions and experiences with consumers. This method is used primarily as Caselles (2008) argues, citing Zeigler (1984), for its "multifaceted" or "perspectival" quality, in the sense that the model and its level of detail is constructed by identifying the elements and relationships of a real system. In order to identify the key elements for building the model, a comparative analysis of theoretical approaches to the design of product groups was performed. It was possible to identify three levels for defining the characteristics required in the design of products: Level 1, Characteristics of the product group (G); Level 2, Internal features of products (P); and Level 3, Product-product interaction and product-consumer interaction (I). Table 1 summarizes the theoretical approaches and the approximation level.

Table 1. Summary of the key design criteria for product systems, obtained from the literature review.

Source	Criteria Group (G)	Criteria Product (P)	Interaction Criteria (I)
Meyer and Utterback (1993)	X	X	
Ulrich (1995)	X	X	
Shenhar, Dvir and Shulman (1995)	X	X	
Meyer and Lehnerd (1997)	X	X	
Stadzisz and Henrioud (1999)		X	X
Blom (2000)		X	X
Jiao and Tseng (2000)	X	X	
Agard (2002)	X		X
Maier and Rechtin (2002)	X	X	
Kovse *et al.* (2002)		X	X
Zha *et al.* (2004)	X	X	
Bürdek (2005)		X	
Hölttä-Otto (2005)		X	
Ngouem (2008)	X		X
Johansson (2010)			X
Luchs and Swan (2011)		X	X
Lau *et al.* (2011)	X	X	
Chai *et al.* (2012)	X	X	X

The characteristics of the group (G) are defined from the first level of approximation, and it is determined based on criteria such as the typology and number of products that make up the group and the relationships, hierarchies and interdependencies between these. On the second level, the product criteria (P) is defined, as well as the subsystems (common and specific), the intra-objectual relations and the means for manufacturing; focusing on the identification of the binding elements of the system (parts and/or specific common components, elements of order and composition). On the third level, the relationships between products and interactions (I) with consumers are established, and this is achieved by linking “soft” qualities (messages, meanings, perceived qualities, etc.), with the “hard” characteristics (material, aspect, performance, etc.). This is crucial, as those “soft” attributes of the product are incorporated from the beginning of the design process, and decisions are made on the degree of complexity in the use and experience. Figure 1 summarizes the conceptual approach to design product systems, based on the integration of the three levels of approximation previously identified.

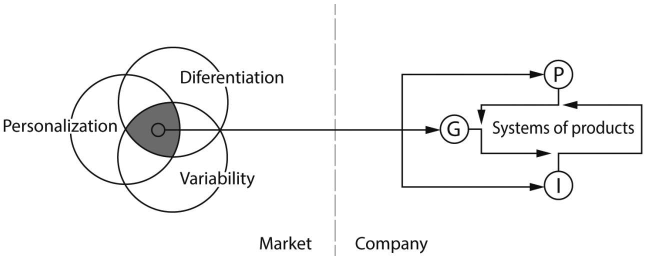

Figure 1. Conceptual model for the design of systems of products.

Research model

This research aims to evaluate the proposed conceptual model. Supported in the characteristics of the systems approach, the ability of this model to efficiently manage the complexity in the design of product systems is studied, identifying how the perceptual characteristics and experience required by consumers (in addition to the functional requirements and performance) are incorporated from the design process’ initial stages; and how the products are defined by criteria derived from the concepts of variability, differentiation and customization.

From these arguments, a hypothesis is formulated:

The configuration of product systems is based on the interaction of three subsystems, which determine the (internal and external) characteristics of products, their relationships and interactions with consumers.

Methodology

To evaluate the hypothesis, a relational quantitative descriptive study is carried out which, as Mejia (2005) argues, is part of the associative type of research, used to find a correspondence between the variables. A survey was applied to 57 international experts in product design, enquiring about their opinion regarding some variables identified in a previous focus group conducted with 6 academic experts with experience in research, teaching and technology transfer. This procedure was adopted by the capacity of expert consultations to establish whether the items of an instrument adequately represent the construct being measured (Barraza, 2007). From a selection of 60 contents obtained in the literature review, 17 were defined in the focus group to be included in the survey. It was determined that the variables would be scored by respondents using a Likert scale of 5 intervals (Elejabarrieta and Iñiguez, 2007). This scale measures the degree of importance of each variable in determining the characteristics of product systems, being 1 for a low-grade and 5 for a high one. Simple statistical analyses were used to prove the scale validity (Flynn *et al.*, 1997).

Sample

Methodologically, convenience sampling (Malhotra, 2004) was performed. The selection of experts is made from the identification of the main authors of the literature review, which showed experts and research centers with more scientific production. A list was prepared with data from 103 experts, which were invited (via e-mail) to participate in the study (the survey was attached in this message). 61 surveys were received (57 valid and 4 invalid), representing 55,3 % of the experts identified. The 57 experts who finally participated in the research are from 22 countries; their areas of expertise are represented as follows: 65 % design (industrial, product, strategic, etc.), 17,5 % engineering (industrial, mechanical, computer, etc.) and 17,5 % social sciences (psychology, marketing, philosophy, branding). Several studies classify the individuals according to their experience; in this study the classification of Liem *et al.* (2009) is applied, in which respondents are classified in four categories according to their experience and occupation level: Beginner, Intermediate, Senior and Expert. According to Popovic (2004), by doing this the sample is representative regarding a specific domain, based on the extensive experience of the experts. Table 2 condenses the characteristics of the group of experts consulted.

Table 2. Expert profiles.

		Education					Occupation			
		PhD	Master	Specialization	Professional	Total	Teaching	Consultancy	Professional Practice	Research
Expert		10	7	1	5	23	18	15	14	8
	%	18	12	2	9	41	32	26	25	14
Senior		13	6	0	0	19	18	8	5	10
	%	23	11	0	0	34	32	14	9	18
Interm.		7	2	0	0	9	9	6	6	3
	%	12	4	0	0	16	16	11	11	5
Beginner		1	5	0	0	6	3	1	2	4
	%	2	9	0	0	11	5	2	4	7
Total		31	20	1	5	57	48	30	27	25
	%	54	35	2	9	100	84	53	47	44

Data analysis

Reliability analysis is applied to establish the internal consistency of the data. In the data analysis, the exploratory factor analysis (EFA) is used to simplify the information obtained from the correlations between the variables; IBM SPSS Statistics V20 software for data analysis was used.

Internal consistency

For reliability analysis, the Cronbach α coefficient was used to assess the reliability of the scale; the value of $\alpha = 0{,}802$ was obtained, and this result is optimal considering the assertions of Oviedo and Campo (2005): the minimum acceptable value for α is 0,70 (below this value the internal consistency of the scale used is low). This study has a high degree of content validity, because the scales of the instrument were taken from the literature (see Table 1).

To validate the hypothesis, an exploratory factor analysis (EFA) with Varimax rotation with Kaiser is applied (Table 3), seeking to identify relationships and associations between variables. The resulting KMO is 0,600, which is located inside the recommended limit Kaiser Meyer Olkin (acceptable level). This positive result is reinforced considering the high values of the Bartlett test of sphericity, and it rejects the hypothesis of diagonality of the correlation matrix, because there are significant relationships between variables, which increases the quality of analysis (Salvador and Gargallo, 2012).

Exploratory Factor Analysis (EFA)

The Exploratory Factor Analysis (EFA) integrates the initial variables in 3 factors, explaining the 51,329 % of the variance (F1 = 25,451 %; F2 = 13,676 %; F3 = 12,020 % (see Table 3). The V19 and V25 variable, are not included in this analysis because their factor loadings are lower than 0,4.

EFA methodology requires allocation of a term for each set of variables. Factor 1 groups the variables V27, V29, V24, V30, V31, V23, and V21, which are characterized by delimiting the set of products that make up the system and determine the structure of their relations (hierarchies and interdependencies), its composition and exchanges between products and consumers. Factor 2 groups the variables V36, V34, V33, V22, and V35, which determine the characteristics of coherence: of the system itself, between products, and between the parts and components of each product. Factor 3 (variables V18, V26, V28, V30, and V20) defines the technical and productive aspects of the products and its relationship with consumers.

Table 3. KMO and factored loads of the variables analyzed.

KMO measure of sampling adequacy Kaiser-Meyer-Olkin.		**0,600**
	Chi-square approximate	339,910
Bartlett's test of Sphericity	gl.	136
	Sig.	0,000
Total variance explained		**51,329 %**
Variance Component 1 (F1)		**25,451 %**
V27. Limits, flexibility and degree of exchange.		0,773
V29. Technical interfaces and protocols.		0,747
V24. Shaped assembly and integration of the components.		0,600
V30. Typology of the system.		0,549
V31. Interfaces and their relationships with users.		0,535
V23. Hierarchical relationships and interdependence between products.		0,535
V21. Number of elements.		0,413
Variance Component 2 (F2)		**13,676 %**

V36. Formal coherence between products.	0,731
V34. Basic geometries, sizes and proportions.	0,706
V33. Formal characteristics.	0,678
V22. Formal relations.	0,664
V35. Materials, aspect, colors and textures.	0,622
Variance Component 3 (F3)	**12,020%**
V18. Define the experiences and use.	0,697
V26. Form, function and use that enhance the price - perceived value.	0,642
V28. Technical characteristics.	0,589
V32. Design concept.	-0,510
V20. Estimated costs.	0,411

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. The rotation converged in 4 iterations.

The first factor is called STRUCTURE (25,451 % of the variance) and obtained high factor loadings on variables V27, V29 and V24, which indicates this factor is conditioned by criteria in which defining the system limits and exchanges with consumers and market; variables V30 and V31 complement this definition level, that define how users will relate to the products. The STRUCTURE factor also determines which and how many items (products) are part of the system and its hierarchical order (V23, V21). The second factor is called ORDER, and it contains high positive results in variables V36, V34, and V33, which establish the elements of formal configuration (intra and inter figural) of products and its relation to the modes of production (V35), leading to the materialization of these criteria. The third factor is composed by variables that determine the COHERENCE and interaction of the system; the experience and the use of products are defined from the conceptual design (V18, V26, V32). This level identifies and describes the qualities of interaction of the system with consumers.

By analyzing the graphical representation of the results (Salvador and Gargallo, 2012), the variables that are capable of determining or characterizing the factor and other variables that influence it can be identified more accurately (see Figure 2).

The STRUCTURE factor (coordinate axis X) is defined by the variables: V21, V23, V27, V29, and V30, which incorporate the features that define the system: relations between products, exchanges with the environment (in terms of interactions with users, energy flows, etc.), typology or "strategy" for best performance and the achievement of the objectives of the system. In the second factor or ORDER, variables V36, V34, V33 and V22 are grouped and defines the system configuration features (intra-objectual and inter-objectual), V30 and V32 variables have great influence, allowing to link the system type and design concept. The COHERENCE factor is characterized by variables V18 and V26, with great influence of the V32 variable, which confirms that the use and experience determine how design is addressed and should be considered at system level. In this way, coherence between products is achieved along with its relationship with the consumer (different degrees of expertise, level of complexity in use, etc.).

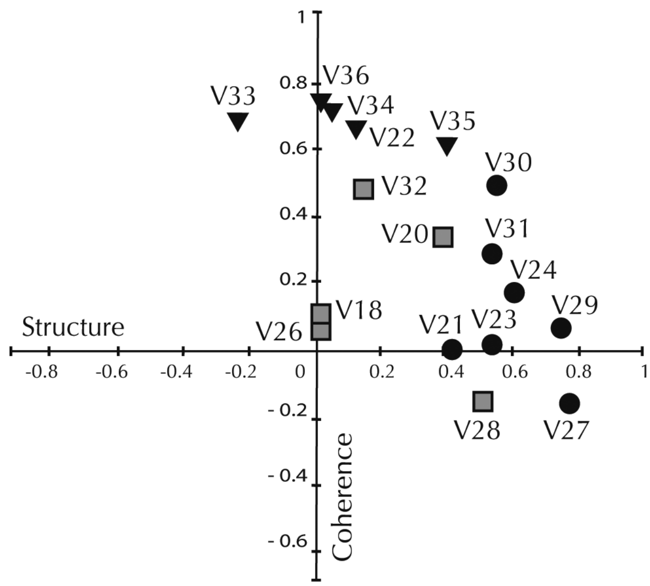

Figure 2. Graphical representation of the results of EFA.

Results

Exploratory factor analysis identifies the key subsystems (STRUCTURE - ORDER - COHERENCE) required for the design of product systems, and are described in the characteristics of the three levels of approach in the design of these systems (Group, Product and Interaction). This analysis also determines how each of these variables (regardless of the subsystem to which they belong) must be developed and evaluated in these three levels. It must be pointed out that experts assign a high value to aspects of configuration, use and experience. This coincides with the concept of differentiation as a determinant of the competitiveness of product systems. It is also confirmed that the competitiveness of enterprises and products should not be based only on technical factors related to the manufacturing and infrastructure. This is explained by the low valuations that experts give to the variables related to these aspects. Three interdependent factors are identified: STRUCTURE, COHERENCE and ORDER. The variables that compose them are not mutually-excluding; on the contrary, it is evident that some variables have important influence on the other two factors.

Discussion

This study identifies new ideas and complementary relationships with existing literature, which are discussed in relation to the concepts developed. In the first instance (from a systemic perspective), it explains how the models of product systems are built from the interaction of three major subsystems: STRUCTURE - ORDER - COHERENCE;

and this interaction determines the internal characteristics of the products that make up the system, the relations between products and the interactions of these with consumers.

One finding of particular relevance is the set of characteristics of the ORDER subsystem, which exceeds the limits of the concepts of product architecture proposed by Ulrich (1995), because, besides from establishing the arrangement of functional elements and specifications of the interfaces between the physical components they interact, it is also determined that these actions must be approached from a broader perspective, involving the user and experience. This approach also extends to the statement by Hölttä-Otto (2005), in the sense that the product can be formed by various alternative orders, where the relationships required by the structure determine the design of products and their evolution over time.

In addition, there is a direct relationship between the proposed model and the approaches of Otto and Wood (2001) where scalability is a property that characterizes these product groups, because the structure determines the correspondence between the elements (modules) and subsets. In proposed model, the COHERENCE component is assimilated to the "strength" to which Baldwin and Clark (2000) attribute the ability to generate connections between the elements of a structure. It has also been found that the criteria associated with the COHERENCE subsystem are coincident with the position of Bloch (1995) and Lee (2010), for whom interaction between form and function by adding hedonic and utilitarian features is an appropriate way of adding value to the product by increasing the number of associated experiences.

Conclusions

Consistent with the literature (Luo and Zhang, 2011; Tseng and Jiao, 1998) and based on the opinion of experts, this study identifies the characteristics and conditions required for the design of product systems, overcoming the typical processes of design (for an individual product) as information is processed efficiently, reducing complexity, and managing this process as a simultaneous and iterative activity from the initial phases of design process.

The methodologies for the design of product families are focused on determining function and production, where the morphological factors and use are integrated only in the final stages of development. This is a contradiction, precisely because these factors are what allow customization and require the incorporation of user criteria as basis for differentiation, as well as their interrelationships, for extrapolating this information to design a wide range of products developed systemically.

It is very important to recognize the high value that experts give to the determination of experiences and use as the origin of the design process. This contrasts with the main approaches of literature, in which the origin of this process is the identification of technical functions and the subsequent incorporation of these into physical elements; which in turn respond to the logic of technical rationality. The systems approach develops the interrelationships between the multiple customer needs, from the initial stages of the design process and throughout the product development process. It is considered that the product (and its many variants) are an integral and integrable system, where the variability is not an "added" function, it is an intrinsic property (built from conceptual design) which allows parallel product design.

This exploratory study had a number of limitations from which the lines of future research are identified. First, this conceptual theoretical focus suggests that the proposed model must be contrasted with cases of market and industry. Another limitation is the link between the variables extracted from the analysis and the terms of systemic modeling. In this sense, a future study focused on standardizing these terms is required.

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