DESIGN OF MODULAR PLATFORMS: APPLICATION TO A PRODUCT FAMILY

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Abstract

This article presents the development of a Product Platform for the design of a Product Family using Modularization techniques. In this way it is possible to obtain derived and differentiated products efficiently and quickly with little effort.

The current work presents the essentials of product platform design and its application to the design of a product family by means of modularization techniques. The platform approach allows derived and differentiated products to be obtained quickly and efficiently with small design efforts, offering a varied supply to the market and facilitating the management of different product generations.

Keywords: *Product family, Product Architecture, Product Platform, Modularization, Commonality, Dendrograms.*

1. Introduction

Most companies have verified that long term success does not depend on one unique product, but on a series of high value articles intended for introduction into expanding markets. However, and at first sight inexplicably, there are many companies that create products one by one. This causes them to fail time and time again, simply because they do not opt for what is common, compatible, or standardized, or for harmony between different products or product lines.

Due to the development of modern technologies and globalization, differentiation from their competitors has become ever more difficult for companies to achieve. In order to maintain market advantage, companies try to provide product variety by means of the differentiation of their product lines. A wider product variety improves sales through the offer of more purchase options.

At the moment, under competition within globalized markets, many companies are using product families to increase the variety of the offer, improve client satisfaction, shorten downtimes and to reduce costs. The key of a successful product family is the platform from which they are derived.

Product platforms facilitate the creation of new high value products, quickly and economically, by means of the use of standard modules, and differentiation by means of other modules. In this way a brand image is created whilst moving large amounts of products into the market at less cost, as it is not necessary to repeat the design process (Aguayo, 2002).

To attain these objectives, it is necessary to define a platform strategy, to later make the analysis and finally the design. The series of stages to be established are shown in Figure 1.

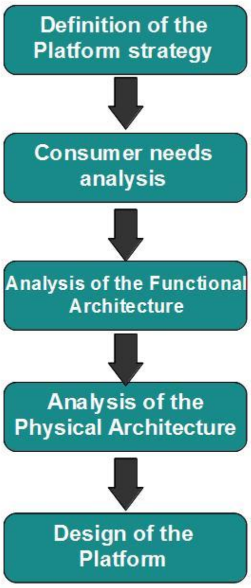


Figure 1. Stages of the process of design of a modular platform.

1.1.- Product Architecture.

The definitions regarding product architecture found in the literature (Hölttä, 2005) converge on the concept of the arrangement of its elements, which constitute their physical structure and the abstract representation of their functions.

The product architecture is an abstract description of the entities of a system (products), of its relationships and their combinations, and by which these entities are organised in physical or nonphysical subsystems of greater complexity.

In the representation of the product architecture, its model or representations can be found in both the physical domain (component and subsystems) and the functional domain (functional blocks of the product). There are different methodologies for the representation of the product architecture, some include both domains and others only the physical or the functional.

1.2.- Product Platform.

Research into the development of product families based on platforms has been led by the need of industry to compete in the global markets, to manage the problem of variety and, under the existing challenges, to provide better quality, to give competitive prices, and to improve the response to the market, all with the minimum complexity in manufacture and production.

Product architecture and modular design have created the base of the efficient product platforms. The Product Platform is thus defined (Simpson, 2001) as:

"The common set of physical or nonphysical modules from which multiple products can be derived in successive generations"

Regarding the methods of design and development (Simpson, 2001), the following methods for the design of a product platform have been proposed:

- Top-Down approach: A company strategically directs and develops a product family based on a product platform and its derivatives.

- Bottom-Up approach: A company redesigns or consolidates a different product group to standardise components to improve economies of scale.

Another form of approaching the development of product platforms (Simpson 2001) is:

- Scale Based Platforms: These are platforms where the products share the functionality, but are all at different levels of execution. Motors of a same technology but of different power.
- Module Based Platforms: The product platform is designed as reconfigurable, so that it can be easily modified and improved through the addition, substitution or exclusion of modules to produce a product family based on the modularity.

1.3.- Modularity.

There are different approaches to defining modularity; the definition given by Hölttä (Hölttä, 2003) is taken as a reference

“A module is a building block of a larger system that has a specific function and some well defined interrelations, through interfaces."

Modularity indices can be used to obtain relevant data about the level of commonality (common elements) in a product family. Each index allows the designers to identify specific points in the design (such as the number of unique parts, etc.), and the comparisons between commonality indices can produce additional information about the influence of the product platform strategy.

1.4.- Advantages and Disadvantages of Modularity

Modularity, together with the platform approach has a series of advantages, among which are:

- A great variety of products can be obtained by means of the use of the same module in multiple products.
- Modular multi systems provide advantages such as reduced capital requirements.
- Modules designed with clearly defined interrelations can be used again in other designs.
- Modularity favours the disassembly and recycling of a product at the end of its life cycle.
- Modularity makes a product more flexible in the face of possible changes.

Among the disadvantages of modularity are:

- Modularity can lead to excessive costs due to over-design and inefficient execution, too many common modules can cause a loss of brand identity.
- High powered mechanical products, in contrast to electronic products, would benefit from an integral design if the objective is the best technical execution. This is because a modular design is probably, but not necessarily, larger, heavy and less energy efficient than a product that has integral architecture. In addition, these effects are difficult for the Design Engineers to control.

2. Methodology for the creation of a modular product platform.

The methodology that allows the creation of a product platform is structured in a series of phases (Chadrasekaran, 2001), which will be discussed in the following sections.

2.1.- Needs Analysis.

The first task to be undertaken in the creation of a platform is the study of the needs of the consumer, observing the selected market segment regarding, according to criterion, the qualities that a product must have.

After collecting information on consumer needs, it is classified into essential and distinctive needs. The hypothesis of consumer needs is based on which consumer needs can be classified, based on frequency and importance, into essential and distinctive. For that, this hypothesis of platform formation from the domain of need, breaks down into three others:

- H1: Based purely on the declaration of the frequency of the needs of the consumers. It is expected that a low frequency leads to a common platform, whereas a high frequency will lead towards differentiated modules.
- H2: Based solely on the weight of the needs of the consumer. The consumer needs of greater weight will lead to a common platform, whereas the consumer needs with less weight will lead towards differentiated modules.
- H3: Based on the consideration of the interaction of the frequency of the consumer needs and their weight. The needs which are highly valued and of low frequency will lead towards the common platform. And those with little weight and of high frequency will lead to differentiated modules.

2.2.- Modularization of the Functional and Physical Architecture.

Different techniques of modularization of the product architecture have been developed, with respect to the functional domain modelling, decision making processes, physical domain, etc., from which the product platform is developed. Some of the most important are explained in the following paragraphs.

2.2.1.- Functional Domain Heuristics.

This method consists of the application of three heuristics on the functional architecture, to identify modules through the previous preparation of a well refined functional model (Murlidhar, 2008)

a) The Dominant Flow Heuristic.

This first heuristic examines each non-branching flow of a functional structure and groups the sub-functions. The flow travels through the functions until it leaves the system or is transformed into another flow. The set of identified sub-functions will define the module in agreement with the flow layout throughout the system.

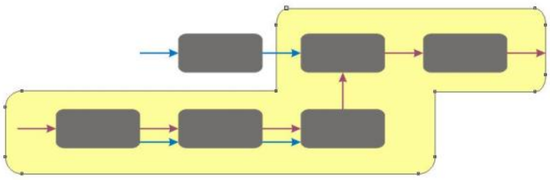


Figure 2. Dominant flow.

b) The Branching Flow Heuristic.

The second heuristic refers to the branching flow and requires the identification of flows associated with the chains of parallel functions. Each branch of a chain of parallel functions defines a potential module. This will be formed by the sub-functions that the branch assembles (Branch being understood technically as a sequential functional chain). All the modules (one per branch) must interact with the product at the point of branching of the flow.

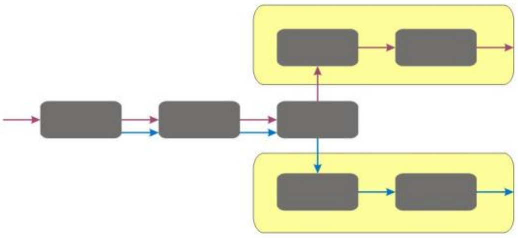


Figure 3. Branching flow.

c) The Conversion-Transmission Heuristic.

The third heuristic is in agreement with the conversion-transformation functions. The conversion sub-functions accept a flow of matter or energy and convert the flow into another form of matter or energy. A conversion sub-function appears as a flow A that is converted to flow B. In many cases, these conversion sub-functions are already components or modules in themselves.

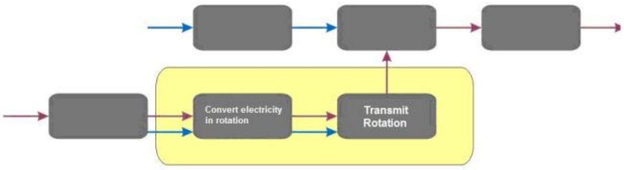


Figure 4. Conversion – Transmission flow.

2.2.2.- Identification of common modules by means of dendrograms.

In this section a quantitative method is described to evaluate the common modular elements. It is based on the measurement of the "distance", which will be defined, between two different modules and in the grouping of modules within an hierarchic dendrogram which will help to decide if the functional groups are sufficiently similar to be replaced by a common module.

Each type of flow is dealt with independently and combined at the end of the distance calculation phase. This approach supposes that all the types of flows are comparable in a spatial dimension. This will define the "commonality" (common elements), or the lack of it, to help in the selection of the common modules for the different platforms.

a) Commonality in the functional domain.

In order to identify common modules in the functional domain, begin by creating functional structures for each product that is considered part of the same product family platform.

The measure of the distance is an n-dimensional Euclidean distance based on the input and output values of the flow of the functions.

The basic steps to follow are the following:

1. Construct functional structures for all products.

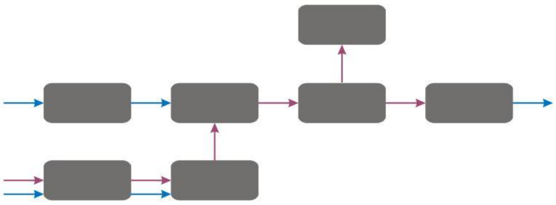


Figure 5. Functional structures

2. Enumerate all the functions (functional blocks) as black boxes.

$$m^1, m^2, m^3, \ldots, m^N$$

3. Characterize all the black boxes related to the input and output flows with their units given by the technical specifications, the consumer requirements or by values of actual flows if it is a redesign of an existing product.

Figure 6. Black box with its inputs and outputs.

The inputs that must be characterised with their attributes are represented to the left of the functional block, and to the right, the outputs will be defined in the same way as the inputs. The number of inputs and outputs will vary based on the needs that the functional block satisfies

4. Check the black boxes of the functional blocks for potential groupings.

The objective is to find out how similar the two modules are; that is to say, what is the distance from one to the other. In order to define the distance between two modules (*mα* and *mβ*), it is necessary to measure the distance between the inputs and outputs of the functional block.

The most effective algorithm will be that which includes the preference in the functions (included in the weight of the equations) of the types of flow, to manipulate the non-additive nature of the flow difference, as well as the value of the growth of flow. The preference of the functions and their weights have to be chosen with caution. For them the distances are divided between the maximum of the value difference of the two variables.

The distance between the outputs *xα* and *xβ* is *sαβ*, where:

$$s_1^{\alpha\beta} = \frac{x_1^\alpha - x_1^\beta}{\max\left(x_1^\alpha - x_1^\beta\right)} \tag{1}$$

The distance between the outputs $y\alpha$ and $y\beta$ is $t\alpha\beta$, where:

$$t_1^{\alpha\beta} = \frac{y_1^{\alpha} - y_1^{\beta}}{\max\left(y_1^{\alpha} - y_1^{\beta}\right)} \tag{2}$$

5. Calculate the metric distance between the functional blocks or the black boxes. The pseudo-distance between $m\alpha$ and $m\beta$ is defined by means of:

$$m^{\alpha\beta} = \sqrt{\left(s_1^{\alpha\beta}\right)^2 + \left(s_2^{\alpha\beta}\right)^2 + \ldots + \left(s_N^{\alpha\beta}\right)^2 + \left(t_1^{\alpha\beta}\right)^2 + \left(t_2^{\alpha\beta}\right)^2 + \ldots + \left(t_M^{\alpha\beta}\right)^2} \tag{3}$$

Next, it is defined that $s1\alpha\alpha = 0 / m\alpha\ \beta \geq 0$, and the distance matrix M will be:

	m1	*m2*	*m3*	*m4*	*m5*
m1	0	*m12*	*m13*	*m14*	*m15*
m2		0	*m23*	*m24*	*m25*
m3			0	*m34*	*m35*
m4				0	*m45*
m5					0

Table 1. Distance between boxes.

Note that matrix M (Table 1) is symmetrical and satisfies all the conditions to be a Euclidean measurement. The dendrogram, Figure 7, is constructed from the matrix by means of the corresponding algorithm.

6. Construct the dendrogram.

The dendrogram is constructed starting with the two modules that have the smallest distance between them. These modules will be connected at a point equal to their distance. The following pair of modules that have not been assembled in the dendrogram are then taken and connected, one to the other, at a distance equal to their value given in the matrix. Modules continue to be added whilst groups of modules are connected to each other in the dendrogram at a distance of the nearest module group. These steps constitute the algorithm for the construction of the dendrogram.

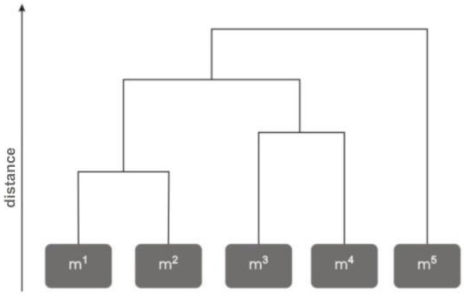


Figure 7. Dendrogram.

b) Commonality in the physical domain.

The algorithm described for the functional domain in the preceding section can also be used in the physical domain, with some small modifications. In the approach in the physical domain the product needs to be broken down to the assembly level, instead of to the abstract or functional level. The input and output functions of the functional domain are replaced by components or sub-assemblies, the input and output requirements and other attributes such as the weight and the volume, when necessary.

2.3.- Creation of the Product Platform.

The elements that compose a product platform are those shared by all the products, in addition to these, there are others that relate to each different product, these are differentiator elements or modules. In the functional design phase, functional blocks are searched for that form modules, both of the platform (standard) and differentiators, in order to later transfer these functional domain solutions to the physical domain and to carry out the production redesign or design. Through the data collected within the analysis framework a possible solution will be reached that will materialize in the creation of the product platform (Tae, 2005). Among the techniques of establishing standard and differentiator modules is that of the modularization matrix, which determines the configuration of the platform and its modules, which have to be evaluated with different indices grouped constituting different metrics.

2.3.1.- Evaluation of the Product Platform.

The **user satisfaction** metric is one of most important. It attempts to measure the degree of need that would be covered, based on the number of requirements and the number of variants (products) offered by the platform.

$$Y_{CR} = \frac{1}{M} \sum_{variants\,i} \left(\frac{1}{k} \sum_{requirements\,j} \left(w_{ij} R_{ij} \right) \right) \qquad (4)$$

wij = Weight of importance of requirement *j* for product *i*.

Rij = Rating for a user requirement *j* for product *i*. Scale 1-10.

K = Nº de Requirements.

M = Nº de Variants.

Ycr = Degree of fulfilment of the requirement of the consumers.

2.3.2.- Commonality Indices.

These indices, based on a component perspective, basically measure the similarity and difference between them within a product family. These indices are not usually focussed on the functional architecture, but on the elements (modules or components) of the physical architecture. Regarding these indices it is possible to emphasise the following concepts and procedures of the calculation.

- Unique, variant and common components.

For the measurement of commonality (common elements) a component or module is defined as the smallest separable element within a product, be it a component, a module or an assembly. Three different types of components or modules are differentiated in the tree which models the product architecture:

- *Unique*: The component that is only used in one of the products of the family.
- *Variant*: The component that has the same function in some or all the products of the family, but its design, structures and material differs slightly between products pertaining to the family or portfolio.
- *Common*: The component that is exactly the same, shared by some or all the products in a family, line or portfolio.

- Degree of Commonality Index (***DCI***)

The degree of commonality index (*DCI*) reflects the average number of common parent items per average distinct component part.

$$DCI = \frac{\sum_{j=i+1}^{i+d} \phi_j}{d} \tag{5}$$

Φj = number of immediate parents component j has over a set of end-items or product structure levels.

d = number of different components in the set of items.

Equation (6) allows the highest and lowest values of the *DCI* to be seen:

$$\begin{gathered} 1 \leq DCI \leq \beta \\ \beta = \sum_{j=i+1}^{i+d} \phi_j \end{gathered} \tag{6}$$

When *DCI* = 1 there is no commonality, that is to say, no item is being used by more than one component in any one of products. When *DCI* = *β* complete commonality exists.

- Total Constant Commonality Index (***TCCI***)

The total constant commonality index (*TCCI*) is a modified version of the *DCI*. Unlike the *DCI* which is a cardinal index (and hence a reduction or an increase of commonality cannot be measured), the *TCCI* is a relative index which has some absolute limits.

Where:

$$\begin{gathered} TCCI = 1 - \frac{d-1}{\sum_{j=i+1}^{i+d} \phi_j - 1} \\ 0 \leq TCCI \leq 1 \end{gathered} \tag{7}$$

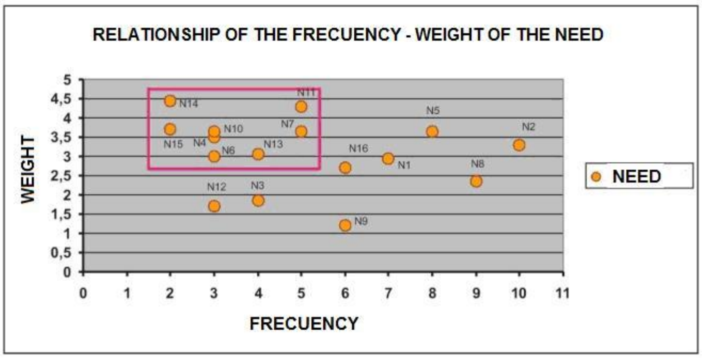
When *TCCI* = 0, there is no commonality, that is to say, no item is being used by more than one component in any one of the products. When *TCCI* = 1 complete commonality exists.

3. Case study.

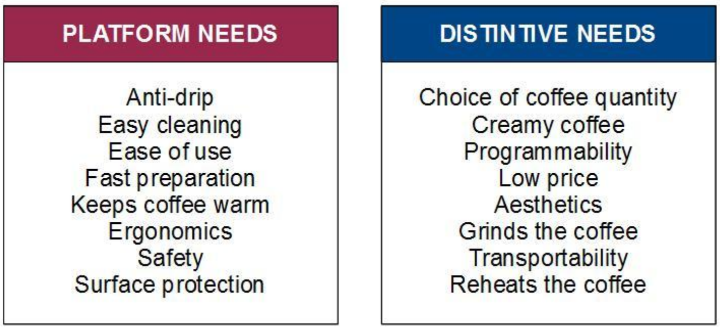
Now the theoretical bases for the creation of a product platform have been represented schematically, a case study is presented that was derived from solving the problem of forming a product platform for a family of 6 domestic coffee machines.

3.1.- Consumer profile.

The first criteria to be considered in the design of the product platform were those of the need to be satisfied (the need domain), to subsequently transfer them to the functional domain, constructing the functional architecture of the product. For this purpose questionnaires were produced in which a sample of the population within the key market segment were asked what they thought were the needs that a coffee machine had to satisfy. The obtained results were not sufficiently valid and a new survey was made in which it was requested that they value the needs derived from the previous study from 1 to 5 in order of importance. The validated results of the second study gave some platform needs (needs that all the products have to satisfy) and other differentiators. These last results are shown in Graph 1 and Table 2.



Graph 1. Relationship of Frequency – Weight of the need



PLATFORM NEEDS	DISTINTIVE NEEDS
Anti-drip	Choice of coffee quantity
Easy cleaning	Creamy coffee
Ease of use	Programmability
Fast preparation	Low price
Keeps coffee warm	Aesthetics
Ergonomics	Grinds the coffee
Safety	Transportability
Surface protection	Reheats the coffee

Table 2. Platform needs and differentiator needs

3.2.- Functional and physical architecture.

The platform of the need domain led to the functional model creating the functional architecture of the product Figure 8. A black box model was used, in which the boxes had inputs and outputs in flow form. Modularization heuristics were applied to this architecture.

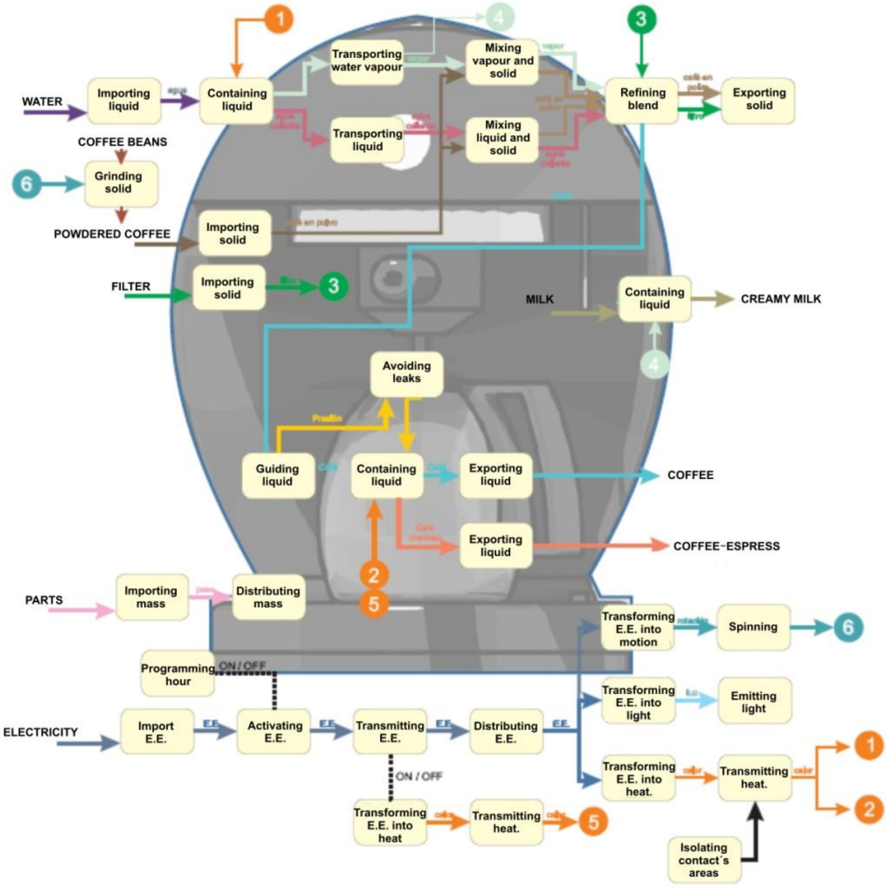


Figure 8. Flow chart of the functions of the coffee machines.

The functional architecture of Figure 8 was studied by means of heuristic techniques oriented to the dominant, branching or conversion-transmission flow. These techniques were used to group the different functions of the coffee machines into functional modules. In order to corroborate the results a more exhaustive study of the functions was made. This time dendrograms were used, which show a quantification of the groupings of the distance between functions, having obtained the model of Figure 9.

Conclusions were drawn from all this data with which it was possible to identify functional modules:

> Electrical Module, Illumination Module, Thermal Module, Stirring Module, Steam Module, Liquid Module, Anti-drip Module, Support Module.

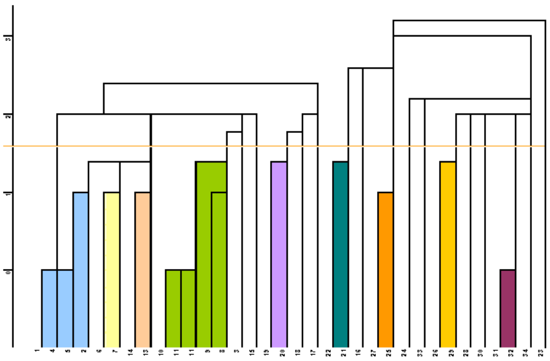


Figure 9. Dendrogram of the different modules

These modules had to be compared with the functional architecture of the initial coffee machines and their Lay-Out viability. To that end, different lay-outs of the three products were produced. This analysis of the functional modules indicated that these could be independent of the product and, therefore, be proposed for integration in any one of the coffee machine models derived from the production design. This criterion is the motor in the search for physical modules, which is why the manner in which the components can satisfy this criterion must be studied.

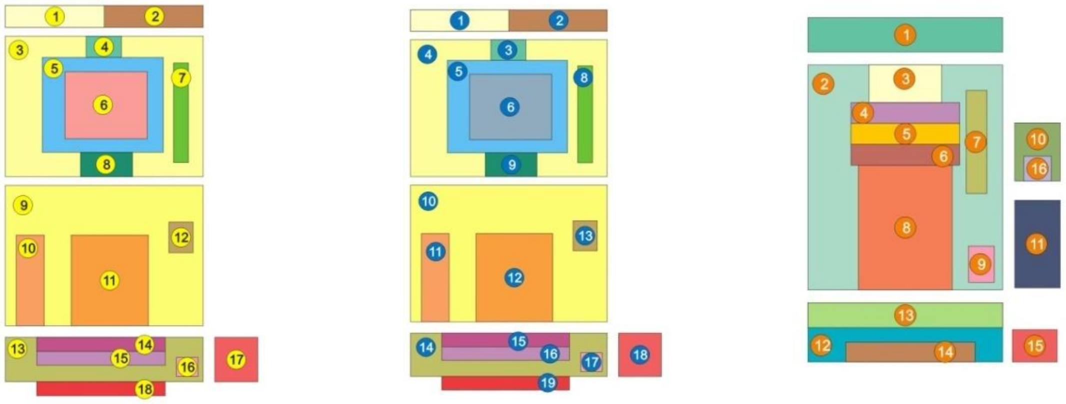


Figure 11. Lay-out of the different coffee machines subject to redesign.

Subsequently the components from each one of the coffee machines were compared, searching for commonality in the physical architecture of products. The components that could be modularized due to the exchangeability between products were those that were common to the different coffee machines. In the produced design these were:

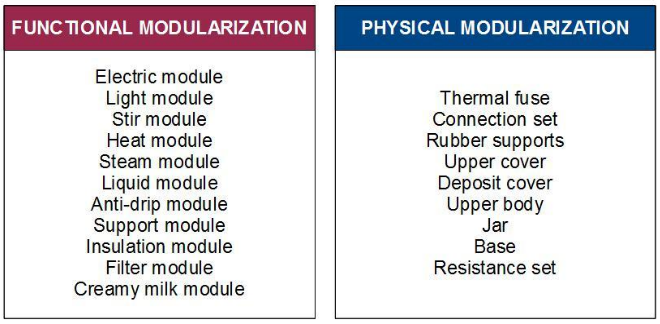
- Thermal fuse, Connection set, Rubber supports.

It was observed that through the redesign of the current components towards those common to and compatible for the three models, it was also possible to find the following potential common modules:

- Upper cover, Deposit cover, Upper body, Jar, Base, Resistance.

3.3.- Modularization.

In the physical and functional modularization some results were obtained that had to be compared to reach a common solution to the objective of the project. To that end, a redesign of the product components was made, whenever necessary.



FUNCTIONAL MODULARIZATION	PHYSICAL MODULARIZATION
Electric module	Thermal fuse
Light module	Connection set
Stir module	Rubber supports
Heat module	Upper cover
Steam module	Deposit cover
Liquid module	Upper body
Anti-drip module	Jar
Support module	Base
Insulation module	Resistance set
Filter module	
Creamy milk module	

Table 3. Modularization Proposal.

3.4.- Product Platform.

From the preceding studies it was concluded that the product platform would be formed by the following components, already shared by the products or redesigned for the platform:

The components of the platform will be	The components of the differentiation modules will be
Cover	
Deposit cover	Timer
Anti-drip valve	Boiler
Resistance	Steam tube
Deposit cover	Filter carrier ladle
Switch	Spray diffuser
Thermal fuse	Drip spray
Upper body	Spray support
Lower body	Permanent filter
Jar	Removable filter
Connection set	Silicone tube
Base	Filter carrier support
Rubber supports	Coffee grinder
Hot plate	

Table 4. Platform components and differentiator components.

Figure 12 shows the modules that constituted the platform and the derived modules, from which all the variety required by the market was generated

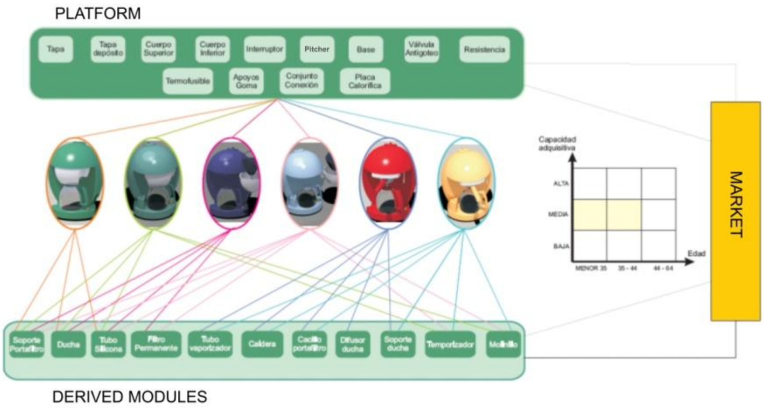


Figure 12. Product platform.

3.5.- Commonality Index.

In order to evaluate the different aspects of the product platform, the commonality index was recalculated for each one of the designed coffee machines.

CI 1= 0.875

CI 2= 0.897

CI 3= 0.886

CI 4= 0.909

CI 5= 0.897

CI 6= 0.920

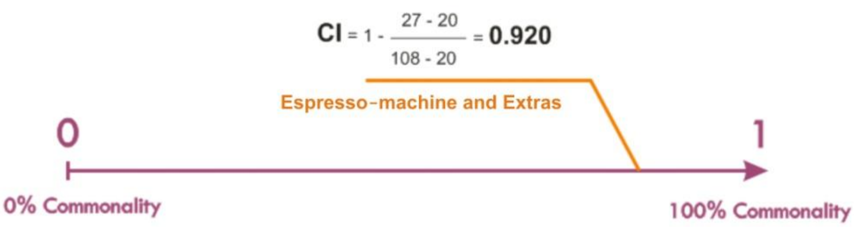


Figure 13.- Commonality Index.

The results obtained through the calculation of the different indices, reveal a high degree of commonality in all the new coffee machines, with the espresso coffee machine with extras having a particularly high index.

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