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Proposal for a Methodology based on Functional Hierarchization for Product Development

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Proposal for a Methodology based on Functional Hierarchization for Product Development

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I. Introduction

The key factor for the product development is design methodology: an innovative and iterative process to design a product by relating functional requirements and customer needs [4]. A technique that encompasses the study and the systematization of a function is the Functional Analysis, which allows the transcription of consumers' needs in a semantic structure that, afterwards, may be broken down into sub-functions until the most basic and simple level is achieved.

Authors such as [2,3, 6,9, 16, 17, 21] describe function and functional analysis from different points of view. However, there is a consensus among these authors that the function deployment technique must be inserted into the stage of concept generation, in which consumers' needs are described and broken down in order to apply creativity tools later.

The functional analysis can be classified in two groups: the function structure and the function tree. Some authors [9, 16, 21] proposed studies on the function structure:a chart that encompasses the functions and their connecting flows. The function tree based on "why-how" approach was a consequence of the Value Analysis/Value Engineering described by Lawrence D. Miles[6]. The most widespread function tree is the Function Analysis System Technique (FAST) by Charles By the way.

Although both functional analysis are well established and supported a great number of projects around the world [1] asserts that function structures demand a high level of abstraction from the designer that can result in ambiguous or redundant functions. Moreover, the function trees do not reflect the connecting flows between the functions and the correlation between the functions and the product components.

Two functional basis to reduce the cases of redundancy and ambiguity were proposed by [9, 18]. However, even if the functional deployment is guided by a functional basis or taxonomy, some cases of redundancy and ambiguity will still remain [1].

On the other hand, some efforts have been made to correlate the function trees to the product components. [25] Proposed the intersection between the FAST diagram and the components by means of the "Removal and Operation" technique. [13] implemented the integration between the Function Analysis System Technique and the Axiomatic Design Theory to boost the capacity of defining the functional requirements and correlate the functions with others design domains.

The debate regarding different approaches for functional deployment is encouraged by [7], who explains that the function definitions are complementary and the coexistence of various techniques is beneficial to the design process and design teaching.

The present paper contributes to the debate about the coexistence of the design methodologies. Assuming that both function tree and function structure start from the product overall function, it is proposed a technique that merges the function structures to the function trees. Thus, it allows a simultaneous visualization of primary and secondary functions, sub-functions, and sub-systems aiming to establish, according to their position, their influence upon an overall function.

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The design methodology described in this research consists of an in-depth and conceptual study of two functional deployment techniques, based on By the way [3] and Pahland Beitz[16]. Section 2 describes different function definitions as well as establishes the function definition adopted in this paper. Section 3 is a literature review about functional analysis. Are search gap is reported in Section 4.The main goal of this paper, which is the proposal of a design methodology based on the literature review and the research gap, is presented in Section 5. Section 6 exemplifies the use of the proposed design methodology by analyzing a Hot Air Popper. Section 7 presents concluding remarks and discusses directions for future research.

II. Function Definition

There is an intense academic debate regarding the function definition. One example of function definition is proposed by[18] and states that a function is the operation to be performed by an artifact or a device. According to [23], function is the relation between the inputs and the output of a system or particular solution, in overall or local positions. Moreover, [9] emphasize that the functions are performed by the products in order to fulfill customer needs.

There are several other definitions for the term function in literature. [24] Explains this fact as a conceptual anomaly: function is a key term but there is no general agreement about its definition. However, it is indicated that the function definitions usually refers to “goals of the device”, “actions with the device”, “behavior of the device” and/or “structure of the device”. Finally, [7] investigated the awareness about the functional concepts among the designers and engineers who worked in product development in industry. As a result, it was noticed that they misused the word “function” for behavior, purpose or performance of a product. Furthermore, when these professionals were asked to describe a functional deployment of a product, many of them neglected the methodologies proposed by literature.

In order to avoid this type of misuse, we will adopt the definition of function as a description of desired or necessary capabilities that make the product accomplish its objectives by using a semantic structure of a verb that indicates an action, and a noun which is the object of the action.

III. Functional Analysis Methods

Functional analysis may be applied to the different stages of product development, but it is usually associated with the concept generation stage, before the feasibility study stage [2, 16, 17, 21, 22]. Due to the ease of measuring, behavior and performance are two terms associated with functions [21].

The functional analysis of a product is described in different ways by literature. According to [21], firstly, one must find the overall function to be carried out so as to describe it in a black box, in which the input and the output of material, energy and signal are considered. The second stage of this technique is to describe the sub-functions involved in the system, so as to guide the search for solutions in order to achieve a better understanding of the problem and to make the correlation between components and function easier.

Following the same line of reasoning [17] describe function modeling starting with the determination of an overall function so as to structure, afterwards, a function tree, with black boxes and establishing boundaries. Also, according to the authors, function modeling allows the creation of alternative structures to meet the overall function by means of (a) division or combination of functions, (b) alteration in specific dispositions, (c) alteration in the type of connection, and (d) alteration in the limit of the system.

A method of function deployment in five steps is described by [22] and [5], so as to divide a complex issue into sub-issues. The first step is based upon the clarification of the issue, including mission, consumer needs and product specification. After that, the issue is subdivided and described in black boxes. At this point, the author emphasizes that the objective is to describe the functional elements of the product without involving a specific technological principle [22]. The second step is to research external information, by means of interviews with users, consulting specialists, patents and the literature. The third step presents the same technique, but the search is internal, based on both individual and collective knowledge. The fourth step is exploring systematically. At this point, the function analysis is developed to generate benefits related to the identification of a solution that may seem irrelevant at first glance, to the adequate allocation of resources, and to refinement upon dividing the issue. Next, it is necessary to combine solutions in a systematic manner. Finally, the fifth step consists of reflection and the identification of opportunities for improvement [5, 22].

The axiomatic design proposes that the design is composed of four domains: the customer domain, the functional domain, the physical domain and the process domain. The customer domain contains the customer needs and/or the attributes the customer requires from the product. The requested needs and attributes are translated into functional requirements inside the functional domain. Design parameters are set in the physical domain in order to satisfy the functional requirements. Finally, the process variables are established in the process domain to accomplish the design parameters set in the physical domain [19]. The correlation between the members of each domain is verified in a “zigzagging” process that requires attention and experience from the design team because it defines the product coupling and the hierarchies for the functional requirements, the design parameters and the process variables [11]. It is stated that products with minor coupling present superior design. The couplings can be organized in a matrix base, making possible the design of large systems such as cargo/public transport [20].

a) Value Analysis (VA)

The functions of a product are classified according to their hierarchy or purpose. The classification of functions according to their purpose allows the determination of use value, which enables the functioning of the product, and esteem value, a characteristic that makes the product attractive to consumers. Besides, use function must be measurable, while esteem function is, in most cases, immeasurable [15].

Regarding the hierarchy, there are the overall functions, the basic functions and the secondary. The overall function explains itself the existence of a product. The primary functions are placed above the overall function and are the ones responsible for making the product work. Without them the product will have its value decreased and may lose the identity. Finally, the secondary functions support or enhance the basic functions [2].

As value analysis (VA) is a systematic analysis of the characteristics of a product, it requires the knowledge of its functioning [2]. Thus, VA is executed by a group of designer selected taking into account their expertise in specific domains related to the product on development process; this group is coordinated by a VA expert [4]. The first step of VA is to generate the functions of the product, asking what the product "does", and not only what the product "is". After determining the functions, it is necessary to organize them systematically in a function tree.

The Function Analysis System Technique organizes functions schematically, emphasizing their relations and hierarchy. Upon developing a FAST diagram, the designing team is questioned regarding (a) the reasons for the existence of the product, (b) the critical path between functions and, (c) the definition of the functions. This happens by using the terms "Why?" and "How?"[3] as shown in figure 1.

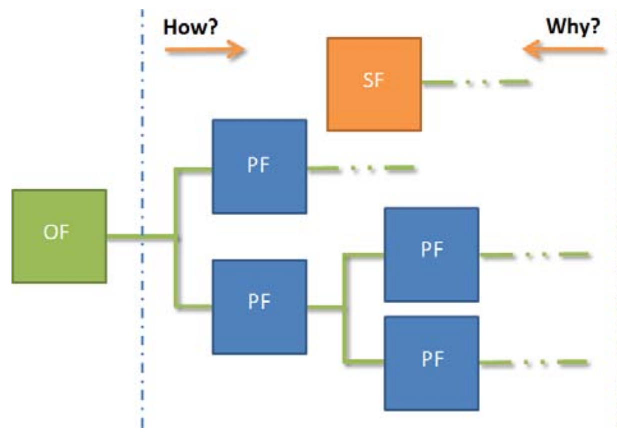

Fig. 1 : FAST Diagram

The functions expanded to the "How Direction" answer how the major function can be performed. In the opposite way, the functions expanded to the "How Direction" answer the reason why the inferior minor functions are performed. The first step in this top-down functional decomposition is the determination of the Overall Function of the product. Going through the "How direction", the Basic Functions are found, than the sub-functions are defined. At the same level of abstraction, Secondary Functions may arise. They may contribute with the performance of the Overall and Primary Functions and/or with the product value, but they also can be harmful or undesired but necessary functions [10].

b) Function Deployment According to Pahland Beitz

The Pahl and Beitz'sFunction Deployment is established above functional structures. It is widely accepted all over the world because it is closer to industrial practice and human thinking system [14]. [16] Define overall function as the overall relation between the input and output of a plant, a machine or assembly. Therefore, input and output, which consist of material, signal, and energy flow, are represented by different types of line in a block diagram. If the overall function is complex, it is necessary to divide it into sub-functions, so as to seek simple and unequivocal solutions.

First of all, the authors indicate that sub-functions must be structured around a main flow. When the function structure reaches the lowest level of complexity, the next step is to detail auxiliary flows and their sub-functions. Thus, function deployment continues until a simpler level is reached, such as described in figure 2. For didactic reasons, these functions are named as Pahl and Beitz functions in this paper.

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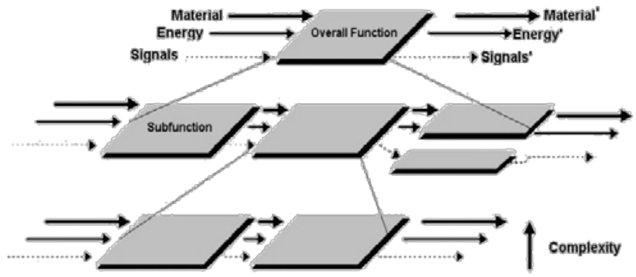

Fig. 2 : Function Structure. Adapted from [16]

IV. Research Gap

The literature presents well established tools and methodologies for the functional deployment in function trees or in function structures. On the other hand, there is a debate about the different kinds of functional analysis, and their possible complementary relations. Also some studies have proposed kinds of hybrid methodologies, however there is a lack of proposals on the explicit merge of a functional tree with a functional structure. The present article intends to contribute to the academic debate by investigating this gap with the proposal in the next section.

V. Proposal for a Design Methodology based on Function Deployment

The methodology described below consists of an in-depth study of function deployment starting from a basic need. This study derives from functional analyses described by Bytheway [3] and Pahland Beitz [16]. As this is a conceptual study with a philosophical approach to these two classical authors in this field, three hypotheses permeate this research: (a) the combination of both function deployment techniques is not possible because they do not present a correlation; (b) the combination of both function deployment techniques presents a similar result if they are applied separately; (c) the combination of both function deployment techniques presents a superior result because it enables an encompassing view of the design.

For didactic purposes, the proposed methodology is divided as figure 3 shows.

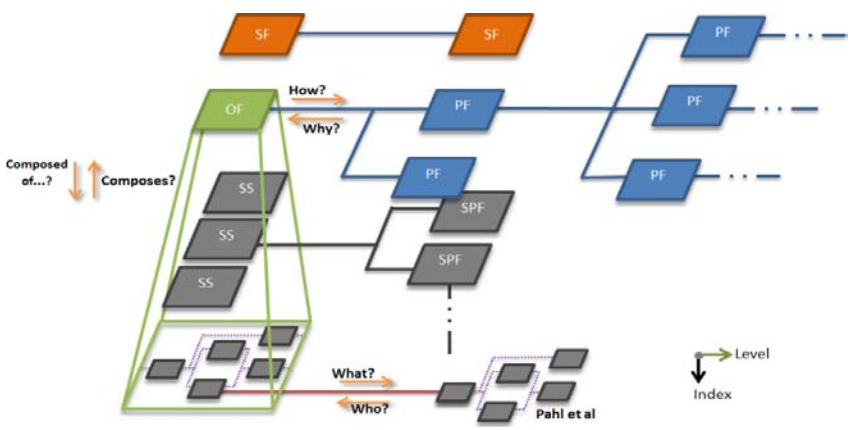

Fig. 3 : Design Methodology based on function deployment

This methodology starts from an Overall Function (OF) and goes on to function deployment with the determination of Primary Functions (PF) and/or Secondary Functions (SF), which, afterwards, are divided into Primary Sub-functions (PSF) and/or Secondary Sub-Functions (SSF), which are related to Sub-systems (SS) that, in turn, make up the Overall Function (OF).

Based on this information, the proposed methodology consists of the following steps:

Step 1: The basic need is described by an Overall Function (OF), which consists of an overall and desired relation between the input and the output of a product, with a view to accomplishing an overall task. In this context, the black box is of most importance so as to indicate the input and output parameters of the system, as in figure 4.

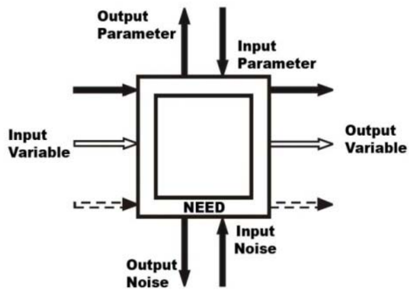

Fig. 4 : Step 1: The overall function and its input and outputs

Step 2: The Overall Function (OF) is divided into sub-systems, which correspond to the components that constitute the overall task. Moreover, each sub-system may be divided into new sub-systems so as to reach the basic sub-system, as [16] propose. Given that, as mentioned before, there is no consensus among authors regarding nomenclature and terms, this proposal indicates that sub-systems should be obtained by means of asking "Composes?" and "Composed Of?", as shown in figure 5. Nomenclature at this stage follows the pattern "sub-system n.x", in which "n" is the level of deployment and "x" is the index of the sub-system at an "n" level.

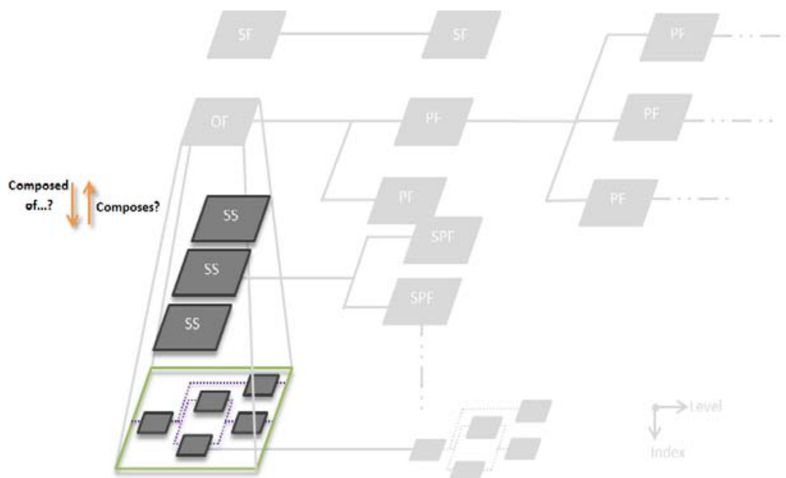

Fig. 5 : Step 2: Sub-systems and components deployment

Step 3: The Overall Function (OF) is divided into Primary Functions (PF), which correspond to how the OF is carried out, as in figure 6. Moreover, each primary function may be divided into new primary functions so as to reach the basic primary function, as [6] proposes. In this case, the terms "How?" and "Why?" are used for deployment. The nomenclature at this stage follows the pattern "primary function m.y", in which "m" is the level of deployment and "y" is the index of the primary function at an "m" level.

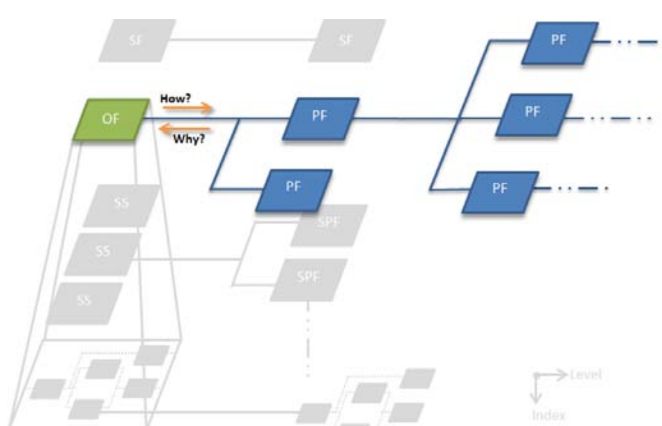

Fig. 6 : Step 3: Primary Functions deployment

Step 4: Secondary Functions (SF) are related to the overall function (OF) and, as it is a combined value, their deployment is indicated by the authors of this research. By doing this, SFs can be divided into new secondary functions so as to reach the basic secondary function, forming the basis for the questions recommended by[3], as indicated in figure 7. Nomenclature at this stage follows the pattern "secondary function m.y", in which "m" is the order of deployment and "y" is the index of the primary function in an "m" order.

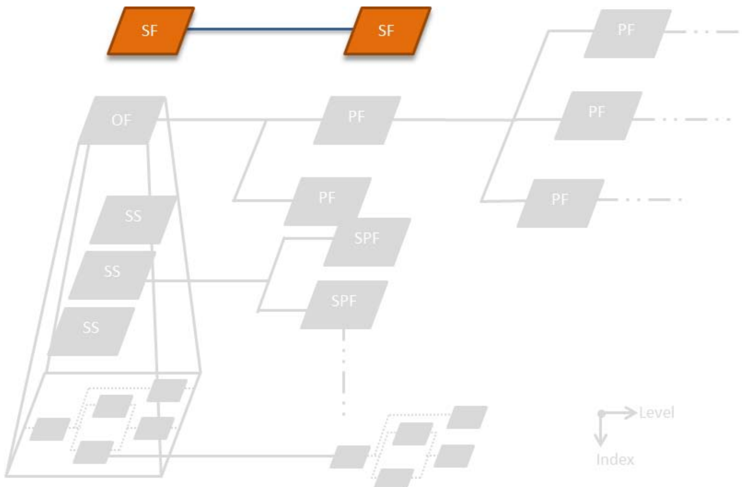

Fig. 7 : Step 4: Secondary Functions deployment

Step 5: Both primary and secondary functions may still be divided into sub-functions using Pahl and Beitz [16] deployment, as in figure 8. Thus, nomenclature at this stage follows the pattern "primary sub-function n.y" and "secondary sub-function n.y", in which "n" is the level of deployment and "y" is the index of the primary or secondary function at an "n" level.

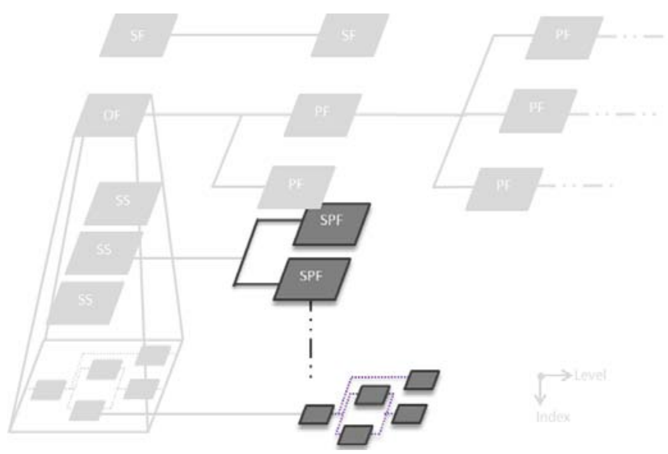

Fig. 8 : Step 5: Sub-functions deployment based on Pahl and Beitz[16] technique

Step 6: After describing the functions, sub-functions, and sub-systems, the last step is to relate basic sub-functions to basic sub-systems. In the end, it is still necessary to eliminate redundancies or repeated elements so as to make the design uncoupled and modular, a design in which each sub-function relates only to a single sub-system.

This methodology shows the sequence of functions, according to levels and order, and their respective relations to sub-systems. Thus, upon generating the complete design, it is possible to distinguish two initial approaches: by presenting alternative solutions to new products and/or by looking for faults in existing products. In a new product, there is the possibility of adding auxiliary tools during the design development, mainly at the concept generation stage, with creativity tools. By doing this, exploring alternative solutions makes innovation and the generation of patents easier. As for existing products, when there are faults in the design, the sequence of the divisions of functions makes the identification of the origin of the error easier. At this point, this research, of a philosophical and conceptual nature, suggests that the combination of both techniques of function deployment produces superior results since they enable an encompassing view of the design.

intrinsically related to functional basis. Once the Hot Air Popper requires little technical knowledge for functioning and operating, we decided to adopt this product as a didactic example to illustrate the proposed methodology.

First of all, it is necessary to define the overall function as described in Step 1. By studying the product and the user manual [8], the main objective of the Hot Air Popper is to "pop corn kernels". After that, the inputs and the outputs indicated by [18] were organized in "energy flow" and "material flow" as shown in figure 9.

The Step 2 connects the flows and the components in order to relate every subfunction to a component. Thus, the product components (pictured in figure 11) were inferred from the functional model adapted from [18] (illustrated in figure 10).

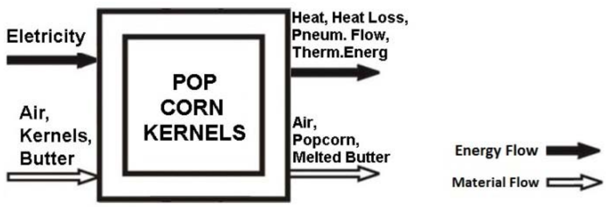

Fig. 9 : Hot Air Popper overall function black box

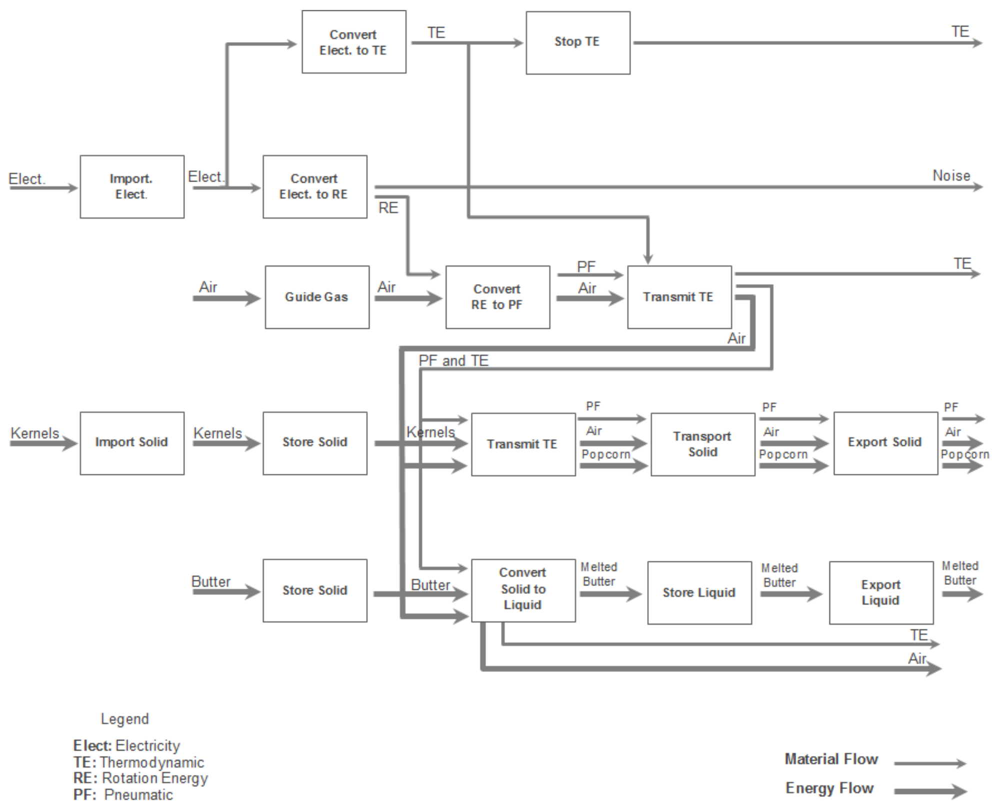

Fig. 10 : The Hot Air Popper functional deployment adapted from [18]

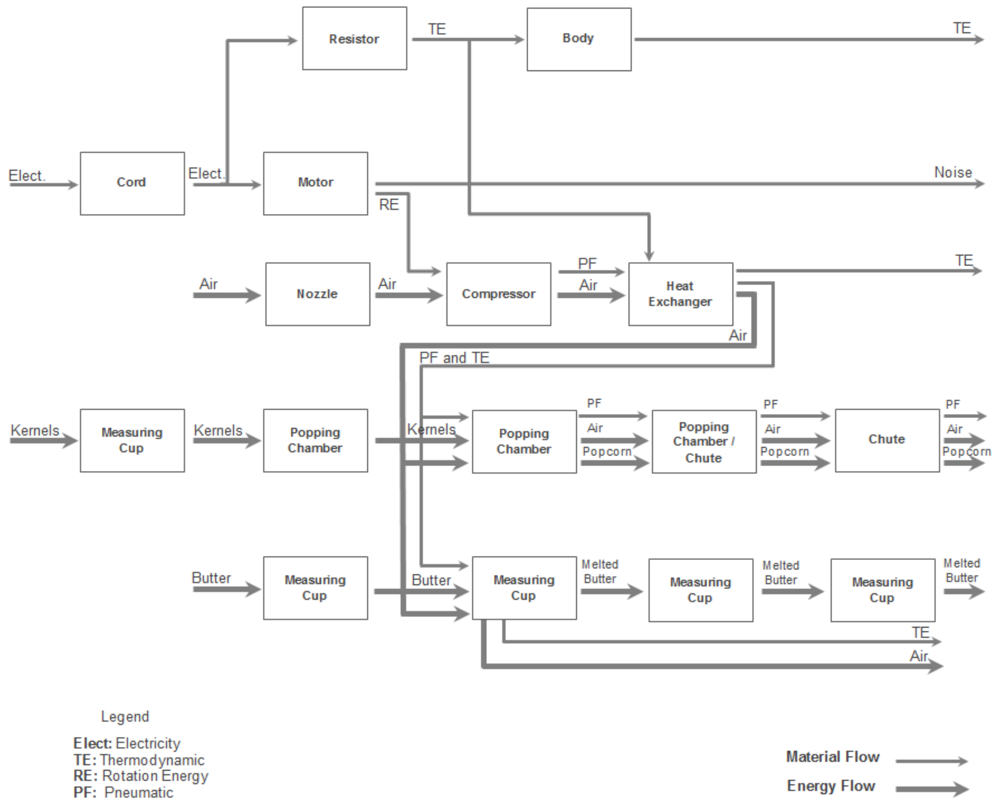

Fig. 11 : The Hot Air Popper components and the respective flows

The third step consists in the deployment of the primary functions based on the "why-how" approach, and the forth step is related to the deployment of the secondary functions. With these two steps, the FAST diagram is completed. To achieve the overall function – pop corn kernels – it is necessary to heat kernels by moving or storing kernels. With the hot air stream it is possible to move kernels, and in the end the air is heated and pumped to form a circuit. The secondary functions are related to melt butter and remove the popcorn. Figure 12 shows the complete diagram.

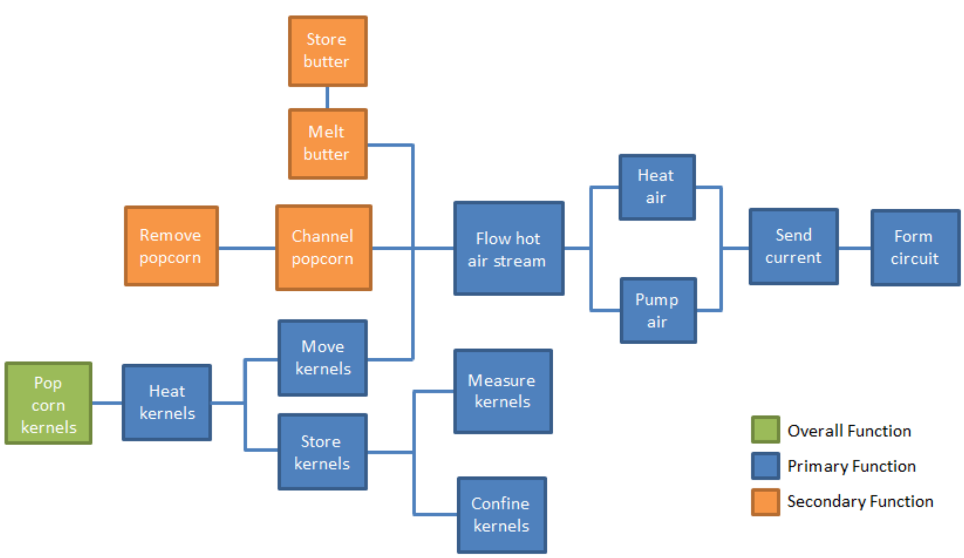

Fig. 12 : FAST diagram of the Hot Air Popper

The step 5 is the execution of the functional deployment according to [16]. As mentioned before, in this example this step is based on the deployment proposed by [18]. Finally, step 6 is the result of the superposition of the function tree and the function structure. It is possible to verify the correlation between the FAST diagram and the Pahl and Beitz functional deployment in figure 13.

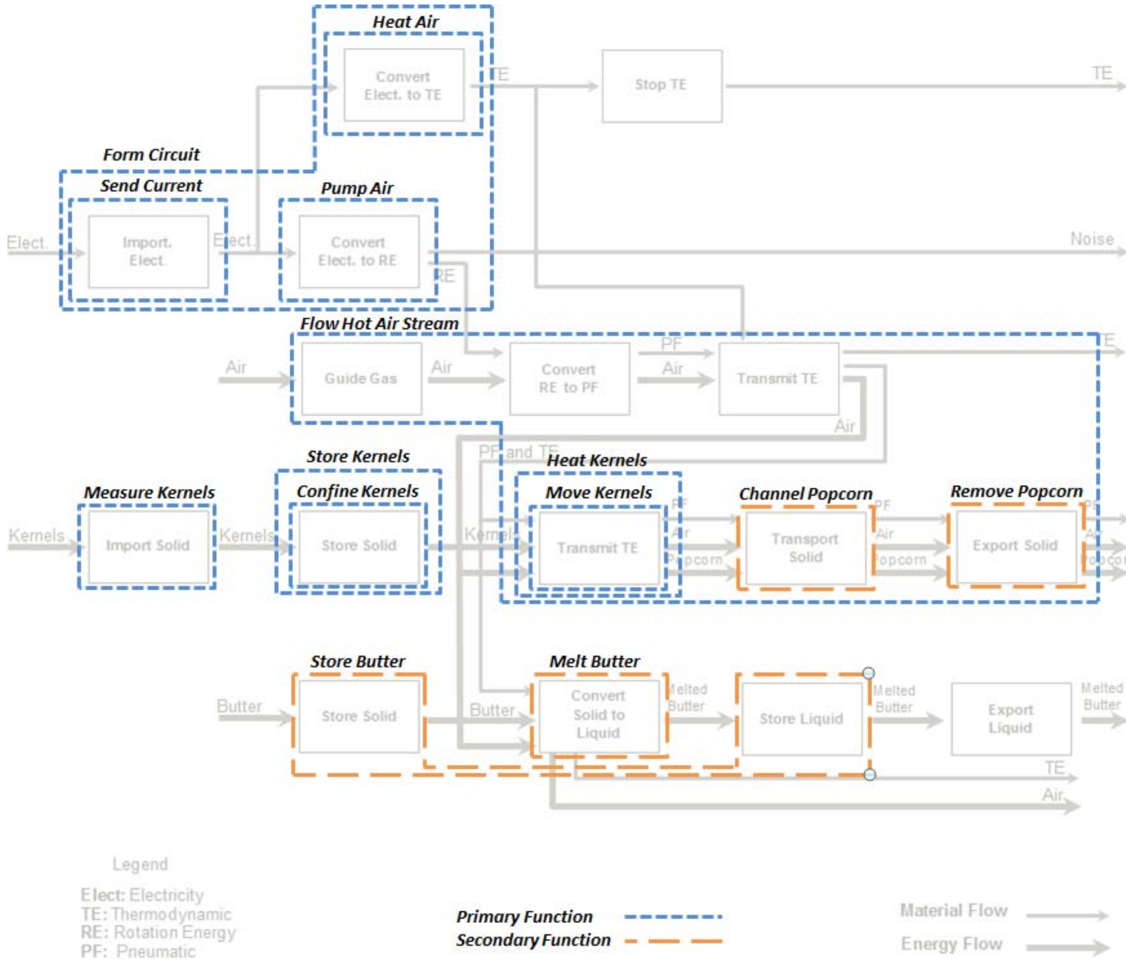

Fig. 13 : The function structure and function tree merge

This example presents a general view of how the proposed methodology correlates the functional deployments and the components. It enhances the design of products focused on the excellence of one characteristic (e.g. quality, manufacturing, cost, sustainability, etc.) because it supports the addition and/or substitution of functions. For example, in a future sustainable version of this product, a FAST function "recover heat loss" in figure 13 would be correlated to the FAST function "form circuit" and/or "heat air". Automatically a Pahl and Beitz function "convert heat loss to electricity" would be added to the function structure, and finally a component that executes this function would be found, e.g. Peltier cell.

In Axiomatic Design the ideal product is decoupled, which means that every single part of it performs only one function [12]. The proposed methodology makes explicit the functional couplings in one single component. For example, by comparing figure 11 with figure 13, the popping chamber performs the functions "move kernel", "heat kernels" and "flow hot air stream"; and the measuring cup executes "measure kernels", "store butter" and "melt butter". If it is necessary, the design team can optimize the butter melting by designing a specialized butter melting component, decoupling this function from the measuring cup. Thus, at the same time that the proposed methodology boosts the identification of couplings, it also supports the insertion of decoupling components.

During the execution of the proposed methodology, it is possible to notice some FAST functions with no correlation with Pahl and Beitz functions or vice versa. In figure 13, for example, the Pahl and Beitz functions "stop TE", and "exportliquid" do not have a correlated FAST functions. Two hypotheses can be drawn: (a) there could be redundant or missing functions in one of the functional deployments; (b) there could be irrelevant functions in one of the functional deployments.

Finally, it is possible to link one component exclusively to primary functions, exclusively to secondary functions or both types of functions. For example, the compressor executes only a primary function ("flow hot air stream"), while the component "chute" executes one primary function ("flow hot air stream") and two secondary functions ("channel popcorn" and "remove popcorn"). The design team can decide on splitting the components to execute exclusively primary or secondary functions, or on aggregating both types of function in one component depending on the value engineering.

VI. Concluding Remarks and Future Research

The theoretical basis allowed an analysis of the definition of the term function within the scope of design methodology. By doing that, a consensus among the several authors there were analyzed was noticed, in the semantic structure of a function based on the use of a verb and a noun. Nevertheless, these very same authors disagree over the categorization of function into hierarchical levels and purpose, and, mainly, when they transpose functions to the stages of functional analysis and function deployment. Upon dealing with tools that aim at both functional study and the classification of each function, it is possible to notice that there are conflicts regarding description and practical application stemming from the lack of clarity of the base terms. This context indicates that the study on the topic is pertinent, since it is necessary to fill in the gap left by both the definition of function and the methodology that approaches functional analysis. Therefore, the methodology proposed in this research aims at the functional study based on a need to form a representation that takes into consideration, at the same time, primary functions, secondary functions, sub-functions, and sub-systems. Considering that the proposal allows the function deployment of an Overall Function (OF), followed by the determination of Primary Functions (PF) and/or Secondary Functions (SF), divisions into Primary Sub-functions (PSF) and/or Secondary Sub-Functions (SSF) that, related to Sub-systems (SS), fulfill the Overall Function (OF), it is possible to approach alternative solutions and/or identify faults. The didactic example illustrates advantages of using the proposed methodology. The correlation between FAST functions and Pahl and Beitz functions is deeply explored, emphasizing the connection between both types of function and the product components. It allows the identification of couplings and the insertion of decoupling components. If there is one type of function with no connection, this function can be considered redundant or irrelevant or there are missing functions in the functional deployments. Thus, the proposed methodology indicates that the combination between FAST and Pahl and Beitz deployment results in a more comprehensive functional analysis by connecting function trees, function structures and components. In future researches the proposed methodology will be implemented by a multidisciplinary team on different areas of expertise such as hybrid vehicular dynamics and artisanal braiding in order to validate the procedure and contrast results.

VII. Acknowledgements

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