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DESIGN OF PRODUCT FAMILIES BASED ON A MODULAR ACHITECTURE

MTOPI FOTSO Blaise E.[1], DJANNA KOFFI F.L.[2], FOGUE Médard[1]
[1] Laboratory of Industrial Systems and Environment – LISIE, Department of Mechanical Engineering and Computed Integrated Manufacturing, FOTSO Victor Institute of Technology of Bandjoun, University of Dschang – Cameroon
[2] Departement of Thermal Enginering –University Institute of Technology
University of Douala, P.O. Box 8698 Douala - Cameroun

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ABSTRACT

Our purpose is to present a methodology concerning the design of product families. From the allocation of the overall function into sub-function, we linked the functional model with the structural model of the product. Our methodology is illustrated by an academic example.

KEYWORDS: Product Family, Modularity, Wheel, Matrix Transfomation

I. INTRODUCTION AND CONTEXT

During the last fifteen years, some essential characteristics of the market have changed. In order to remain competitive, companies must meet consumer's needs and expectations. The fast reactivity and adaptation of firms to this changing environment is strongly related to an advanced control of their internal mechanisms. They compete in five dimensions: price, quality, flexibility, delivery and service. In addition to cost and quality criteria, a tendency to decrease the life cycle of product and increase product diversity is observed. In response to these market changes, companies develop mass customization strategies. Mass customization strategy is designed to support mutually contradicting priorities of price and variety wished by the consumer.

Two linked questions are put in light: what degree of variety is need and how to manage and produce this variety with low costs of design and production. The approaches and strategies of design of product families for mass customization is well know [6], [11]. Multiple products are developed based on product families sharing a common platform. Many firms are pursuing modular product architecture design strategies in order to shorten new product development lead-time and to introduce quickly new product variants at reduced cost.

This paper is organized into four sections. Next section presents a short literature review, section 3 describes the functional approach and section 4 develops the structural approach, section 5 establishes a link between these two approaches

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II. LITERARURE REVIEW

II.1. Architecture and modularity

The literature gives a significant amount of work focusing on developing methodologies for the design of product families, [3], [8], [15]. We can find several design and manufacturing strategies to offer some variety that begin with commonality metrics. Similar systems produced by firms have different product architecture design is due to different design and technologies choices, [7], [13]. "Product architecture" is the arrangement of functional elements of a product into several physical building blocks, including the mapping from functional elements to physical components, and the specification of the interfaces among interacting physical components;

Ulrich [12] defines product architectures as “the scheme by which the function of a product is allocated to physical components”. A key feature of product architecture is the degree to which it is modular or integrative. In modular architectures, functional models of the product map one-to-one to its physical components. On the other hand, in integrative architectures a large subset of the products functional models map to a single or small number of components. Eppinger [2] claims that the product architecture is also the scheme by which “the chunks of a product interact.” Product architecture choice depends on the innovation and standardization policy of the firm.

A typology of product architecture may be given as follows: architecture can be integral or modular and can be split into 3 sub cases to the way in which modules are interconnected with one another, [13].

An ideal architecture is one that splits the product into practical and useful modules. Modules as subsystems of a product are bounded as a unit which presents identifiable functions. In complex products, the chunks of physical components are complex systems as well.

II.2. Product family

A product family is defined as a set of distinguished products whose main functions are similar; it is a set of final products composed of a large number of constituents [13]. It is possible to identify similarities and differences in the individual products of the family. Variety is manifested in a set of generic items and a set of variants involving changes and their relationships [5]. Product families’ modeling includes two aspects: representation of a generic structure and dynamic of the process variant derivative. Previously, some works were developed in Laboratoire d’Automatique de Besancon [1], [14].

A product family may find its origin in a differentiation process of a base product or in an aggregation process of distinct products. In the first case, the family represents a product series with different technologies, optional parts and functions due to the product evolution and demand for diversity. In the second case, the family represents the standardization of a set of products whose functions and main components are similar. In both cases, the goal is to form a group of products to reduce their variability and, therefore, to decrease investment and production costs, [3], [4], [11].

Product design is an evolutionary process from high level of abstraction to detailed low levels of our description. The family description consists of a functional model and a structural model.

As every system, a product family has a hierarchical organization. At the functional and the physical levels, the product is decomposable in sub – systems, them-selves composed of modules or constituents.
Our work focuses on the design of product family based on a modular architecture and it is founded on previously developed works in Laboratoire of Besancon. The objective of this paper is to specify the articulation between the functional domain and the organic domain. Our methodology will be illustrated by an academic example: a car wheel family.

III. FUNCTIONNAL APPROACH

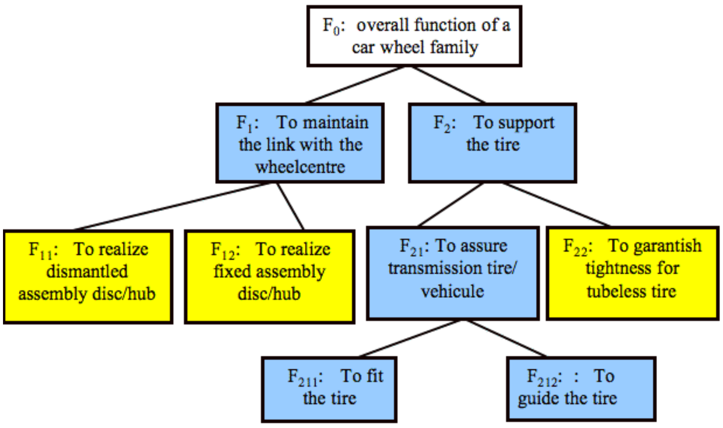
Functional modeling, also known as functional decomposition is the process of breaking the overall function of a product into smaller easily solvable sub functions. Pahl & Betz [11] provide an overview for such a functional decomposition process.

The functional model of a family describes the organization of the functions of each of its products. A product function (also called functional requirement) is the product aptitude for fulfilling a user’s desired task or for satisfying an user’s expectation. We refer to this kind of functions as *main functions* (or service function) to differentiate from internal functions of the products and specify the intent of components and subassemblies in the product. In other words, internal functions represent the decomposition of the main functions into sub-functions. Thus, products in a family have the same base set of main functions with eventual, optional main functions, which are specific to some products. Subsequent functional breaking up may produce differentiable or similar sub-functions for products in the family. The functional model is a hierarchical description of the function decomposition. At the highest level, there are the main functions that define the product intents, and at the other levels there are the sub-functions, which establish how main functions will be achieved by components and subassemblies [12].

Associated with the functions, we have functional constraints. These constraints establish the boundary on acceptable solutions and describe dependencies between functions and/or sub-functions. In the multi-product context, constraints also specify diversity of the functions.

In our example, the wheel is composed of the rim and the wheel center. The family offers the choice of two types of rims (tube type and tubeless) two rim diameters (13 and 16 inches) and two kinds of flange (B or J), so we obtain a family of 8 products. Figure 1 illustrates the functional decomposition. A relation of membership bounds these different levels between the functions.

Figure 1:



Functional structure of a wheel family

On this figure, the relations of membership between functions are highlighted. We can now establish a typology of the functions in the setting of the families of products that allows us to distinguish three types of functions: the constant function, the variant function and the partial function [16].
Constant Function: the function is identically applied on products with the same parameters and the same constraints: F_{11}, F_{12}, $F_{22,}$

Variant Function: F_1, F_2, F_{21} F_{211}, F_{212}, these functions are realized in the eight types of wheels, but the parameters are variable (type of assembly, diameter, type of flanges).

Optional Function: function, which are only present of some product

F_{11}: concerns only wheel with dismantled wheel centre

F_{12}: concerns only wheel with fixed wheel centre

F_{22}: concerns only rim with tubeless tire

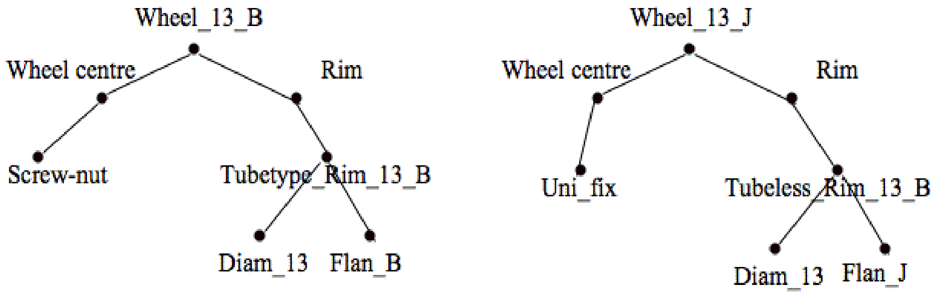
This functional decomposition is also translated in the physical domain (components, connections, subassemblies). The more similar products are, the more unified or standardized the assembly system will be. Therefore, the main objective in designing a product family and its corresponding assembly system is to develop a set of products which correspond to functional requirements through the most standardized set of components and production processes

IV. STRUCTURAL APPROACH

All family of products contains a set of products possessing some similarities between them. These similarities express themselves as well at the functional level (as we presented it to the previous paragraph) as at the level of their material constitution (components and common or similar links).
In this section, we are interested in the generic nomenclature concept and in the establishment of a components typology and of the links in a same product family. This typology, as we will further see, is essential to the realization of a model of representation of product families.

A composed product is a set of components manufactured in accordance with some assembly process. Independently of the order of the components assembly, a composed product can be considered as a functional arrangement of constituents and of sets of constituents. Djemel in [1] qualifies the description of such an arrangement of *nomenclature of product*. All product variants of the family share a common structure.

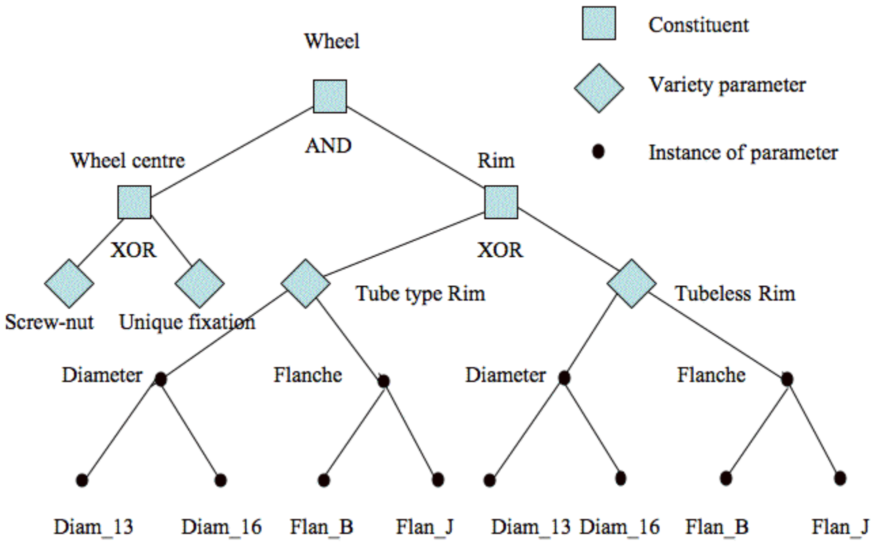
Figure 2:



Two examples of distinctive structures of wheels

Once the distinctive structure for each product in the family has been developed, they must reunited into a generic structure. So we obtain a hierarchy comprising constituents of the family [6]. At the first level we can see (AND tree) a structure, which reveals the topology of the family. At the second level, we placed variety parameters, which represent different instances of a particular component, and at the third level, we put in light variant parameters of the component.

Figure 3:



A generic structure representing variety in a wheel family

V. FROM THE FUNCTIONNAL MODEL TO THE STRUCTURAL MODEL

Staditsz in [14] well clarifies the definitions of nomenclature of product, of functional subassembly, of functional equivalence relation, of generic component of product family and generic nomenclature.

The analysis of the functional equivalence relations of the elements of the eight types of wheels leads to the constitution of nine equivalence classes materialized by the following matrix:

Table 1. Matrix relation between the F_i functions and the classes of equivalence

$$\begin{bmatrix}F_0\\F_1\\F_{11}\\F_{12}\\F_2\\F_{21}\\F_{22}\\F_{211}\\F_{212}\end{bmatrix} \cong \begin{bmatrix} S_0 &&&&&&&& \\ & S_1 &&&&&&& \\ && S_2 &&&&&& \\ &&& S_3 &&&&& \\ &&&& S_4 &&&& \\ &&&&& S_5 &&& \\ &&&&&& S_6 && \\ &&&&&&& S_7 & \\ &&&&&&&& S_8 \end{bmatrix} \begin{bmatrix}Cl_0\\Cl_1\\Cl_2\\Cl_3\\Cl_4\\Cl_5\\Cl_6\\Cl_7\\Cl_8\end{bmatrix}$$

The F_i functions are those presented on the figure 1.
$\{S_0\}$ achieves the F_0 function: overall function of a wheel family and S_0 is the set of the 8 variants.
In order to better structure and to permit a better exploitation of the matrix, we identified one generic constituent by functional equivalence class.
Cl_1 = {Wheel centre} = $\{S_1\}$
Cl_2 = {Screw Nut}) = $\{S_2\}$ }; Cl_3 = ={Unique Fixation =} = $\{S_3\}$
Cl_4 = {Rim} = $\{S_4\}$
$Cl_{5=}${ Tube type rim, Tubeless rim } = $\{S_5\}$; Cl_6 ={ Tubeless rim } = $\{S_6\}$;
Cl_7 = {Diam_13_B, Diam_16_B, Diam_13_J, Diam_16_J} = $\{S_7\}$;
Cl_8 = {Diam_13_B, Diam_16_B, Diam_13_J, Diam_16_J} = $\{S_8\}$;
Every element of an equivalence class achieves a function and we can establish some membership relations between components classes.

$\{S_8\}, \{S_7\} \subset \{S_5\} \subset \{S_4\} \subset \{S_0\}$

Linked to the typology of functions, we define three kinds of generic constituents of a family:

Constant component, variant component and optional component

Constant component*:* A generic component is qualified of constant if all the functions it achieves are constant; this definition is founded on the hypothesis that in a product family, material differentiation is justified by its functional model, (S_2 S_3 S_6).

Variant component: In this case, one of the functions which the component achieves is variable, the others are constant functions. This type of component is present in all the types of product family.
Optional component: generic component is qualified of optional if at least one of the function which it achieves is optional, the other may be constant or variant, (S_2 S_3 S_6).

This example puts in light how it is possible to structure technological solutions obtained from the functional analysis. But we think that this kind of results is strongly linked to the knowledge on the product. And this aspect needs further developments about traceability, project memory and knowledge management.

VI. CONCLUSION

In this paper we present a methodology to pass through functional requirement to technological solutions in the case of product families; the tree structure provides a way to characterize variant derivation at different levels. The analysis of the functional equivalence relations between these elements leads to the constitution of equivalence classes materialized by a matrix and after that we define a diagonal block matrix (transformation matrix) which links functional characteristics and generic components. This method provides a means to describe variants of the product family. It can be used to present both final products and components.

But the geometrical links between the components do not remain identical in the set of the types of product. Because the components are liable to change from a type of product to another, some links can also be different according to the type of the product in the family.

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