Applying Modularity and Commonality Concepts in Product Family Design

Eman A. Heikal[1]

[1]*Assistant professor at Canadian international college, Cairo, Egypt*

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Abstract - *Market increasing competition escalates the challenges facing manufacturers to satisfy the needed diversity of products while keeping design and production cost of products as low as possible. Modularity and commonality in product design have been recognized as a smart tackling technique for the stated challenge through offering high variety of products at lower total costs. Despite the importance of modularity and commonality in product family design, most of previous research papers focused on discussing modularity from module level design perspective or product level design perspective. Other research papers focus on discussing the commonality concept of product family design level. For the stated need and importance of modularity and commonality in designing product family, this paper documents the needed information for applying modularity concepts in product design. The paper is discussing certain topics such as product family definitions, and types, as related to commonality concept. It also discusses modularity types is essential issue of product family design. Critical remarks that should be considered during the product design phase.*

KEYWORDS: Modularity, Commonality, product family design, platform design, Automotive, Electrical appliances & electronics applications.

1. INTRODUCTION

1. Modularity and Design concepts

Gershenson et al. (2003) defined the module as "the component or group of the components that can be removed from the product non-destructively as a unit, which provides a unique basic function necessary for the product to operate as desired".

Amie C. Stryker (2010) defined the module as "a group of components or sub-assemblies that perform one or more functions. A module has at least one interface with other modules within a system or subsystem". Katja H¨oltta¨-Otto, Olivier De Wec 2007 has defined the module as "it is commonly an independent chunk that is highly coupled within, but only loosely coupled to the rest of the system".

A group of Modules are used for composing products according to certain product design architecture. Generally modules that composing products could be categorized into two main types which are Unique modules and Variant modules. Unique modules have specific geometry and function that cannot be performed by any other module within the product family, While, variant modules function can be performed by another variant modules. Consequently, any unique module cannot be replaced by any other module. While, variant module can be replaced by any other variant module. It is important to highlight that in order to increase commonality, variant modules only could be replaced by standardized common modules

Product Architecture

Conceptually, product is assumed to be composed of certain "functional building blocks". The arrangement of these "functional blocks" in certain discipline is known as "product architecture". The definitions of these "basic physical building blocks" of the product regarding their functions and their interfaces with the remaining of the device determine product specific function and capabilities. Ulrich and Eppinger 1995 stated "the product architecture (PA) represents the technical product in early phases of product development. Ulrich and Eppinger 1995 stated that: "The product architecture (PA) is the assignment of the products' functional elements in terms of their physical appearance. The physical elements are organized into building blocks (modules), which are a combination of different components that carry a specific function." As shown in figure 1

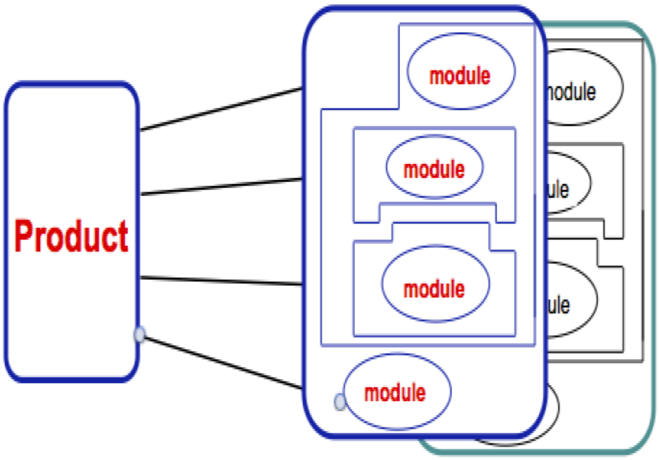

Figure 1 : A systematic diagram of product architecture (PA)

Product architecture types

Baldwin and Clark, 2000 categorized the product architecture which known as product structure into two main types: Integral product architecture or Modular product architecture.

According to Ulrich 1995, A product architecture is said to be modular when Chunks could implement one or a few functional elements in their entirety (each functional element is implemented by exactly one physical chunks, their interactions between chunks are well defined and are generally fundamental to the primary functions of the products. Additionally, the change of a module during design can be performed independently without the need to change other modules". According to Ulrich 1995, a product architecture is said to be integral when Functional elements of the product are implemented using more than one chunk where a single chunk implements many functions. The interaction between chunks are ill defined and may be incidental to the primary functions of the products. Ulrich 1995 stated that: "a fully modular architecture means that a change made to one component does not require a change to other components". Baldwin and Clark, 1997 refers to the personal computer as a good example for a "modular architecture product". In which the hard drive, the processor, the monitor, within other parts are developed, assembled and manufactured by different companies.

Product family versus Product platform

A product family is "a set of similar products that are derived from a common platform and yet possess specific features/functionality to meet particular customer requirements. Each individual product (family member) within a product family is called a product variant or instance". They pointed out to product family is developed for objecting specific market segment while each product variant is developed for addressing a specific subset from customer requirements that segment. Platform of the product family is formed when product technologies and Common structures are bing shared within product variants "Jiao et al 2007".

"A product platform is a set of common elements like underlying technical components, parts or technology that are shared across a range of the company's products. Also, new derivative products can be developed and launched by the company based on a common product platform". Timothy W. Simpson (2005)

2. Modularity definition, types, and benefits

Modularity is the most crucial characteristic product's architecture. Modularity is a property that describes how replaceable the components or modules of a system are. ... Modules can be removed, replaced, or upgraded without affecting other components. For example, most desktop computers are modular because they have easily removable and upgradeable parts. Modularity is proportional property of the product architecture. It is rarely said that products are fully integral or modular. But, it could said that a products exhibit less or more modularity than proportional to other products.

Actually, modularity concept can be applicable on three design levels which are module level, product level, and product family level. Also, modularity concept is associated with various benefits. Thus, various definition of modularity are arisen that highlighted one of these modularity characteristics or benefits and concerned with one or more design levels. Some of these definitions are discussed below.

Modularity

One of the definitions that developed by Sosale et al. (1997) demonstrated the independence feature of modularity. He defined component modularity as "the level of independence of a component from the other components within a product. The more independent (or disconnected) a component is (i.e., the more "degrees of freedom" a component has), the more modular it is." However, this definition concerned with the product itself and cannot be helpful for demonstrating modularity on a product family level. Sosale et al. (1997) developed other definition related to the concept of sustainability. He defined the Modular design as the design that can group components into easily detachable modules such that they can be easily re-used, re-manufactured. He also pointed out that the material compatibility should be considered for recycling apart from ease of disassembly". Their definition concerned with the ease of application of end of life operation on a product itself. Katja Holtta-otto and olivier de weck (2007) developed a modularity definition that is applicable to the concept of modularity on a product family level. They defined modularity as "using the same module in multiple products enabling a large variety of products while using more common component types than if the different products did not share common modules". Their definition clarifies the commonality feature of modularity that is applicable on multiple products. This definition involves the component sharing modularity type.

Types of product modularity

Actually, it is important to point out that there are various types of modularity. Ulrich and Tung 1991 categorized modularity into six types based on to their interfaces and component customizability and their arrangement. They are: 1) "component-sharing modularity" , 2) "component-swapping modularity" , 3) "cut-to-fit modularity", 4) "Mix modularity", 5) "bus modularity", and 6) "sectional modularity".

Component-sharing modularity is the modularity that involves using one core module in constructing various products. A typical example of such type is the Elevator. Despite, one elevators are typical. However, each building required specialized design for the elevator. Using common modules within products of the product family is an illustrative instance of Component-sharing modularity as shown in fig 2.

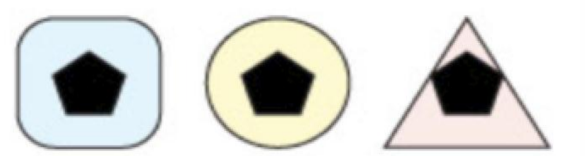

Fig 2: Show Component Sharing Modularity

Component-swapping modularity is the modularity that involves selecting different characteristic modules on standard product to produce variant products within the product family. A typical example of such type is the personal computers, where different characteristics modules could be selected for customized computer. This customized computer could have faster processor for instance as shown in fig 3.

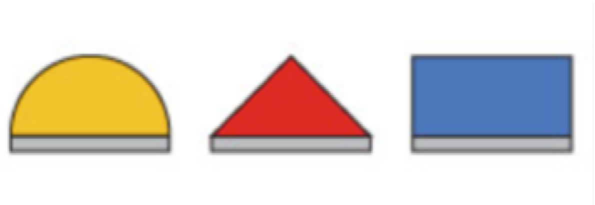

Fig 3: Show Component-swapping Modularity

Cut-to-fit modularity is the modularity that involves modules dimensions modifications to suits customers needs. A typical example of such type is shortening eyeglasses arms for to suit different individual faces as shown in fig 4.

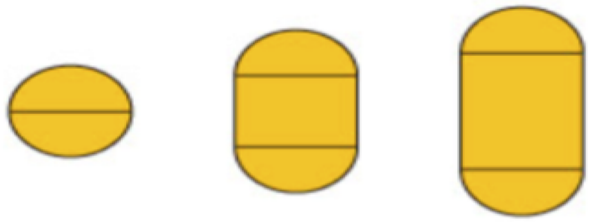

Fig 4: Show Cut-to-fit modularity

Actually "Mix modularity" is similar to "component-swapping modularity". However, the characteristics of the components is changed after its mixed with other components. It is like mixing independent constituents together into a final blend, such as mixing various paints together yield a particular desired color as shown in fig 5.

Fig 5: Show Component Mix Modularity

Bus modularity" is the modularity that involves matching of components any selection from a predetermined set of component types to make product variants. Bus modularity is most often exhibited in electrical and electronic products with busses, such as computers and circuit breaker systems. Bus modularity is also exhibited in track lighting, where light fixtures can be placed at various locations on a track, and shelving systems, where the shelves can be moved to higher or lower location along the brackets installed in the wall or case.

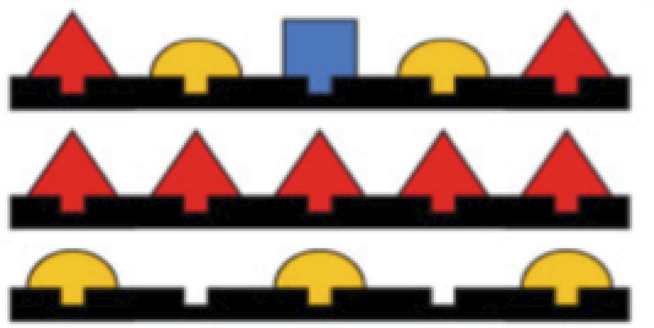

Fig 6: Show Bus Modularity

Sectional modularity" is the modularity that involves the mix and match from of collection of components chosen from a set of component types to be configured in any arbitrary to obtain product variants. The most basic form of sectional modularly can be demonstrated with Lego blocks. A seemingly infinite number of items can be built from a set of Legos. Another common example of sectional modularity is the sectional sofa system. Many different pieces of the furniture can be combined to form an uniquely shaped sitting area.

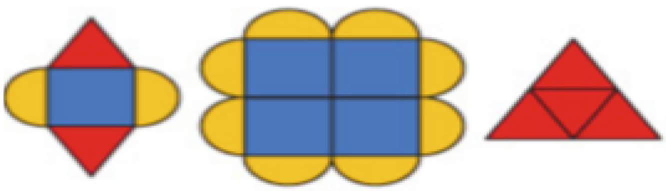

Fig 7: Show Sectional Modularity

Other classification of modularity Design modularity and Modular production are other important modularity classification. The well understanding of these classification is important for applying the modularity concept within the design of the product family.

Design modularity is defined by Mikkola & Gassmann, 2003 as "a strategy for developing new products using standardized interfaces with the shared components in product architecture to permit and facilitate the replacement of components among the product families".

Modular production is defined by Yang et al. (2004a) as designing the production process so as to produce complicated products through by designing and manufacturing modules at various sites and then collect them together to produce the full system. The Modular production divided the whole manufacturing processes into sub-processes. Each sub system could be performed simultaneously or in different sequential order which allow the independent production of product's components and components standardization and before the products final assembly.

Benefits of modularity

Actually, applying modularity in designing products and product family has humorous benefits related to design and production and supply chain, Mass customization, Delayed product differentiation, Benefits related to life-cycle and sustainability, and other extra benefits.

Gershenson et al. 1999 pointed out to modularity benefits related to design and production. They confirmed that modularity is associated with Flexibility in meeting changing processes which allows the designer to control the impact of various processes modifications or requirements on the product. This flexibility permits delaying the design decisions until the needed information is become available without delaying the needed process for developing the product. Sosale et al. (1997) added a recommendation which is manufacturing modules separately for optimizing equipment utilization. They suggested that common modules should be standardized to enhance production quality and efficiency and minimize production costs. Sosale et al. (1997) sated that modular design support parallel development. This achieved through dividing the design task into smaller tasks and then the interface between these tasks are determined. Then, they reused the existing design with minor modifications incase of employing modular architecture. This minimizes the time and the upgrading effort of the existing product.

Ishii et al. 1995 discussed modular design advantages related to the whole supply chain which includes streamlined suppliers, lower inventory rates, lower works in progress, shorter process time. McDermott and Stock 1994 added that employing common parts reduced lead-times and minimized manufacturing costs.

Baldwin and Clark 1997 discussed the benefits of modularity that support mass customization. They stated that modularity allows customers to mix and match modules and components to form the finial products that satisfied customers needs. They also, pointed out to the flexibility of modular designs that allows the responding to the needed functional requirements modifications through time that are associated with customer needs changes , and the requirements for product to perform various functions at various times. Bremner 1999 pointed out to $1.7 billion savings of Volkswagen that result from the product late differentiation through their use of product architecture commonalities through platforms. They referred to illustrative example of Mercedes that employed modularity in action and used postponed manufacturing. Only purchased the needed modules at the assembly time of a vehicle and this increase its response for customers orders without keeping. Sosale et al. (1997) discussed two important noticeable life-cycle benefits associated with modularity which is related to the ease of Maintenance and applying of recovery operations. Maintenance and Fault analysis of product are enabled easily. The problematical module can be specified and replaced easily. Applying recovery operations including reusing and recycling is easy for the detachable modules and components.

Graedel and Allenby 1995 stated that modularity has vital benefit at the end life of products which known as product retirement. Modularity facilitate and increase the reusability and manufacturability because the modular module itself can be replaced to upgrade the product or modify it. Also, remanufacturing and recycling is easier and consume less time and cost than applying remanufacturing operations on less modular modules because it requires lower separation costs .

Ulrich and Tung's 1991 listed other modularity benefits related to the overall advantages of modular products which includes:

1) Economies of scale results from using same components within different product families, 2) facilitating products upgrading because modules have standarardized interfaces within products which easily replaced by upgraded ones disregarding the hassle of interfaces modifications incase of integral products , 3) Increasing products varieties from lower number of components, (4) Decreasing order lead-time due to the use of less components,

Hopwood 1995 added the benefits of product modularity related to electronics manufacturing as follow: 1) Reduced assembly time, 2) Facilitate the re-working of fault assemblies, 3) Minimized labour cost, 4) Flexibility in responding to changed needs, 5) lowered inventory costs, 6) Reduction of development and Design cycle cost reduction. Therefore, the countless benefits associated with the employment of modularity concept in product design enhance the chance of a company to satisfy various customer needs at reduced cost.

3. Commonality definition and benefits

Commonality definition

Commonality is the most crucial characteristic for product's platform design. Commonality is a property that describes how well product design uses standardized components. Also, it describes to which extent product platform utilizes the same modules or standardized interfaces among the products within the product family. Moreover, it describes how same basic product could be used for manufacturing different full products when assembling on it different modules. Since Commonality is a relative property that different within different platform and product family designs. Thus Commonality indexes are needed. Dong and Chen (2005) defined Commonality Index as a measure of how well the product design utilizes standardized components. A component is any inventory item (including a raw material), other than an end item (finished product), that goes into higher-level items.

Ashayeri and Selen (2005) define commonality as "the number of parts/components that are used by more than one end product, and is determined for all product families". While Labro (2004) stated that Commonality is "the use of the same version of component across multiple products. It is a cost-decreasing strategy in a stochastic-demand environment because, by pooling risks, the total volume of the common component can be forecasted more accurately". Mirchandani and Mishra (2002) stated that "Component commonality refers to a manufacturing environment where two or more products use the same components in their assembly". Meyer and Lehnerd (1997) defined commonality as "a group of related products that share common characteristics, which can be features, components and/or subsystems. It is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced".

Benefits of Commonality

There are countless benefits applying Commonality in platform and product family design. These benefits related to planning and scheduling, inventory cost, products lead time, investment safety stock, and other benefits. Md. Abdul Wazed *et al.* (2010) and Bremner (1999) pointed out to commonality benefits related to planning and scheduling. They confirmed that commonality facilitating the planning and scheduling in addition to reducing the processing time resulting into higher productivity. It simplify schedule, planning, and control, thus it speed up product development process.

Zhou and Grubbstrom 2004 pointed out to commonality benefits related to inventory. It reduced inventory level as well as safety stock cost. It reduce the needed set up time; hence, it enhances flexibility and improve productivity. Both Zhou and Grubbstrom, 2004 and Ma el al, 2002 pointed out to the reduction of products lead time. Ma el al, 2002 added that since commonality is associated with larger lot sizes; therefore, it enhances scale of economics. Baker el al 1986 added that Commonality allowing the firm to minimize its investment in safety stock at the same time it maintaining the level of customer service. Labro 2004 sated that, Commonality results in offering a high variety of products at the same time of requiring a low variety on operation. This results into lower costs .Thus, Mirchandani and Mishra 2002 sum up that commonality allows greater product variety through shifting the push-pull boundary toward the customer. Commonality increases work in process flexibility and decrease number of setups needed. It enhance operations economics of scale, facilitates quality improvement, enhance supplier relationship and reduce product development time.

Therefore, the countless benefits associated with the employment of commonality concept in designing or generations of products or a product family enhance the chance of a company to satisfy diverse customer needs at lower cost. This account to the economics of scale in production procurement, and distribution. (Kim and chhajed, 2000).

4. What is the relationship between Modularity and Commonality?

Employing the commonality concept within the design of the products within a specified family cannot applicable without the consideration of two types of modularity. They are Component-sharing modularity and Component-swapping modularity. The Component-sharing modularity is the modularity type that permit the use of common module across different products within the product families. The Component Swapping modularity is the modularity type that permit the use of two or more alternative types of a component or module with the same basic product. The Component-swapping modularity concept facilitates the Component-sharing modularity concept. The component sharing modularity and component swapping modularity are identical except that the "swapping" involves different components of the same basic products and "sharing" involves different basic products using the same components. The difference between them lies in how the basic product and components are defined in particular situations. These two types of modularity will result in different product variants for the same product family. Accordingly, these two types of modularity are crucial to increase the module commonality across products of the same family or different families.

5. Critical issues in applying the modularity in product family Design

1. The modules that used in designing products across the product family should be characterized by having independence features. This will enable interchangeable modules or replacing modules in the product family design so as to produce different

product variants without any consideration of modules interfaces modification.

2. The modules used in building products family should be easily detachable, so that variant module is allowed to be replaced by other modules easily.

3. There are many types of commonality known as Component-sharing modularity, Component-swapping modularity, Cut-to-fit modularity, Mix modularity, Bus modularity and Sectional modularity. The most important of them are component-sharing and component –swapping modularity. The component sharing modularity and component swapping modularity are identical except that the "swapping" involves different components of the same basic products and "sharing" involves different basic products using the same components. The Component-swapping modularity concept facilitates the Component-sharing modularity concept.
4. It is important to design the product family considering the application of modularity design concept, so that the interfaces are standardized and module selection and replacement is the only focus disregarding the hassle of the module interfaces.

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BIOGRAPHIES

Assistant Professor at the Canadian International college.

Earned Phd in Mechanical Engineering, Design and Production specialization, Ain Shams University 2020.

Hold Msc in Mechanical Engineering, Industrial specialization, American university in Cairo 2015