Lucian BÂRSAN, Anca BÂRSAN

CONSIDERATIONS UPON DESIGNING MODULAR CONSTRUCTIONS FOR IMPROVING THE PRODUCTS ASSEMBLING, MAINTENANCE AND RECYCLING PROCESSES

Abstract: *Modular constructions are frequently used in industry because of their multiple advantages. Used from the antiquity as a measuring system that ensured good proportions for the objects or buildings, the module is used in present industry as a tool for improving the product maintenance, repair, upgrading, and/or recycling. Modular constructions can be assembled and disassembled easily, facilitating the post-use actions like subassemblies reuse, or materials recovering for the recycling process. An important aspect of this paper is that designers should create the modular solution even from the conceptual design stage and build a structure of functions based on well motivated arguments and which can easily be brake out according to technological possibilities, product functioning and assembly solutions.*

Key words: *module, constructive design, conceptual design, assembly, maintenance, upgrading, recycling*

1. INTRODUCTION

The theory of engineering design describes a procedure consisting of four main steps to be followed in order to design a product [1]. Conceptual design stage represents one important step in which the general function and the main sub-functions of the future product are established. The function structure is build based on the list of requirements, reflecting (besides others) the client necessities. Therefore, the product should perform the required functions and, for this reason, the designer should identify the most suitable working principles. The structure of functions needs to be optimized considering the constrictions imposed during the design process. The optimization performed during the conceptual design stage should respect constrictions specific to the constructive design stage, as a subsequent step, and from this reason, designers must anticipate not only the product functioning, but also the way it should look like. From this reason, the constrictions are related also to materials, production technologies, assembly/ disassembly, upgradability and different options post-use, ergonomics, or aesthetics, issues specific to the embodiment design stage.

Building the most suitable structure of functions, able to permit a natural flow of material, energy or/and information, optimal both from the perspective of functionality and aspect, is a difficult job for designers and involves establishing a hierarchy between objectives [7]. Consequently, one can choose between several traditional objectives usually described as "Design for production, Design for assembly, Design for recycling, Design to allow for expansion" etc, the others remaining desirable, constrictions during the design process.

In the context of building the function structure, it is necessary to follow one of the flows earlier mentioned. In most of the cases, the main flow should be followed. This will permit a logical sequence of functions, which will result in a natural and complete sequence of function carriers. Analyzing this structure may permit identifying some parts of the product that can work independently. In this way, the function structure becomes more complex, and more detailed permitting the identifying of some functional modules. These functional modules can create the fundaments for building a modular constructive/embodied structure.

This paper will emphasize the advantages of implementing a modular solution from the early stages of the design process and the benefits for production, assembly, maintenance, disassembly, repair, upgrading and post-use options, like components or subassemblies reuse and materials recovery and recycling.

2. MODULAR CONSTRUCTIONS

The use of modules and modular constructions is quite old and the motivation resides in designers' wish for obtaining good proportions for their products. It was a measuring system meant to implement a certain ratio starting from a unit which may be part of the construction (intrinsic module), or not (extrinsic module) [5].

Modern industry changed and extended the original understanding and use of modules and yet it became more than a measuring system, it became a designing system. The concept of unit remains, but the whole is no longer designed as a multiple of the module dimensions, yet a structure (of functions, or an embodied one) divided into modules according to some constrictions imposed by the product (good) functioning.

By extending the motivation and the means to achieving such goals, modularity became a successful solution for so many situations. Designers may choose a modular construction when they have a significant difference of reliability between parts/subassemblies of the same product. This difference may occur as a result of different levels in estimated material reliability, or excessive wear (bearings, for example) or moral usage (the product aspect or some functions become obsolete). The advantages of modular constructions are so many, facilitating the product designing, fabrication, assembly, and disassembly for maintenance, repair, or end-of life.

Many of the design objectives can be fulfilled by creating modular constructions. However, the objectives in order to be fulfilled, the creation of such a construction should start long before the constructive design stage.

Therefore it is necessary for designers to create a structure of functions which can permit such a type of construction even in the conceptual design stage.

3. CREATING THE STRUCTURE OF FUNCTIONS

The consequences of creating a *modular structure of functions* are multiple and generate other constrictions in the conceptualization process. It is also necessary to learn that these constrictions may generate *side effects*.

The conceptual design stage involves, as a main objective, the identification of the *general/overall function* [3]. This can be formulated creating a connection/relationship between the system's inputs and outputs, based on the *requirements list,* which, by the way, should be based strictly on real necessities. The next step is of major interest when designer's intention is to create a modular construction. Breaking the overall function into sub-functions represents starting the implementation of the "*modular thinking*" (Figure 1). This is because each sub-function should be fulfilled by physical, chemical, or biological processes. A physical process fulfilled by the selected physical effects and the determined geometric and material characteristics results in a working interrelationship that fulfils the function in accordance with the task.

The place where the physical process actually takes effect is the working location. A function is fulfilled by the physical effect, which can be obtained in the conditions given by the working geometry, i.e. the arrangement of working surfaces and by the choice of working motions [7].

Building the geometry and establishing the systems able to create the working motions is part of the constructive design, therefore the formal design of the product will be subordinated to the constriction imposed by the modular functional splitting. The components design should respect the constrictions regarding the necessary geometry that can ensure the functions fulfilling. The material choice is close related to this constriction; therefore the components' materials might be influenced by the modular concept, i.e. the structure breaking into modules. Thus, the geometry and the materials characteristics, combined with the physical effects results in the working principle.

Some complex products may need several working principles included into a single physical construction. These can be very different, involving specific materials and surfaces for fulfilling each function. The general principle of simplicity, combined with the core of the engineering design activity, which is solution optimization, results in the necessity to find solutions to fulfil more functions using the same principle. This might complicate the problem of dividing the structure into modular units.

However, as difficult may seem in this stage, dividing the structure into *independently functional units*, it should be performed no later that now. Figure 1 illustrates the principle of breaking down the general function and building the structure of functions also considering creating the functional units as a constriction. The structure of functions is for a washing machine, a product in which a modular solution should be preferred for maintenance, repair, and recycling reasons.

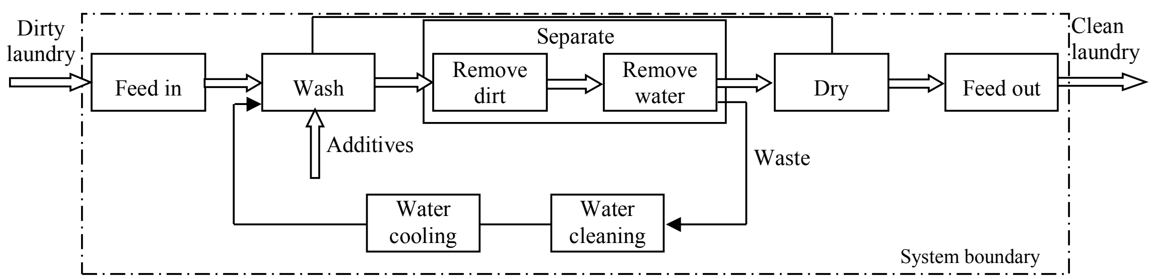

Fig. 1 The structure of functions built on modules.

Obviously, the modular construction is a solution which will not interfere with the product good functioning. The structure of functions has been build, which respects the main flow, which is a material flow. The structure can be optimized considering the modular thinking and thus the structure is changed and the function carriers are gathered according to this perspective [3]. The washing machine has a cylindrical drum (geometry) and uses a rotational motion (physical effect) both for washing (function I) and for drying (function II) the laundry. In this way, the constructive solution involves a single geometry and one physical effect for fulfilling two functions; the model is one module, two functions.

The structure resulted in this way helps the designer to build the physical construction making easier for him the volume splitting. Breaking off the volume modelled as a whole usually is difficult and is based on technological reasons and having a functional fundament.

In the following chapter the design theory presented will be discussed on examples and the advantages for the maintenance, repair and recycling, will be relieved.

Making a construction based on a structure which has not been conceived as modular, probably will result into a non-optimal solution with problems in dividing it according to the functional units.

4. MODULAR STRUCTURES FOR ASSEMBLY MAINTENANCE AND REPAIR

Designing modular structures will result in several important advantages, like simplifying the assembling processes with already known benefits. In time, the initial solution can be improved with fewer costs because only some subassemblies should require upgrading or redesign. Materials, processes can also be changed. A new product, with improved characteristics can be designed and produced faster and with less cost. Also, different products can be produced starting from a modular basis.

In case of repairs, the access to components should be facilitated because modules can be disassembled and replaced with new ones, possibly upgraded ones.

The picture in Figure 2 illustrates the idea of using modular components in building a range of products. The basic module is in triangular shape and another two smaller modules that connects them in order to get a planar or 90^0 connection are provided.

The assembling solution involves designing components that are complementary in shape to each other. Supplementary, the modules are fixed using standard components, screws, and nuts.

This combined assembling system permits the furniture height adjustment by shifting the relative position between the modules. In this way, the furniture can be adjusted to fit the anthropometric dimensions of the user.

For this product, maintenance and repair is simple, any damaged module could be replaced with minimum of intervention. Modules of different colour and texture/material may be combined in order to fit the user needs, and according to the activities performed in the area where the furniture in placed and used.

The example presented is a simple product with only few modules in its structure. In this case, the modularity results mainly in a range of products. However, this simple product can be easily repaired because the production of spare parts is simple. The user doesn't need to buy but three different components and will be covered in any situation.

4. MODULAR STRUCTURES FOR RECYCLING

The last stage of the product lifecycle is known as the "end-of-life" [6]. The ecodesign principles impose finding the optimal solutions to permit reducing the product environmental impact. Therefore, the solutions should permit the product reusing considering, or not, the possibility for upgrading. In case this option is not possible, the materials should be recovered and re-introduced into the "cycle", in a process called recycling. Recycling involves collecting and dismantling the out-of-use product. The optimal solution for dismantling is to disassembly the product, in opposition with shredding it.

Obviously, the disassembly, as a reversed process to assembly can be facilitated by the solutions adapted in the design process, both in the conceptual, and in constructive design stages [2].

Adopting a modular design solution, results in obtaining not only a cheap and easy disassembling process, but in recovering the initial modules of the product in good condition. Hence, they can be used for building new products with a minimum of investment.

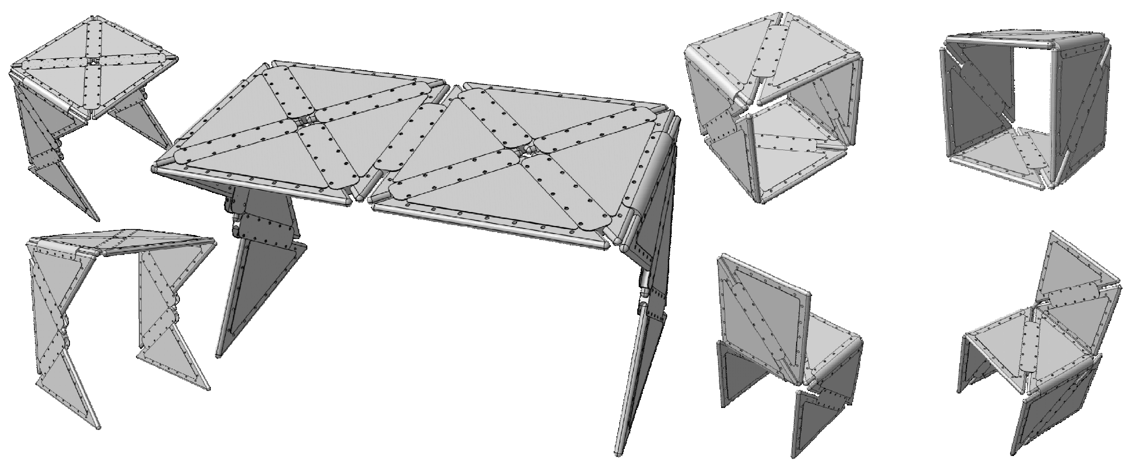

Fig. 2 Modular furniture design.

The modular solutions determine a shorter and easier design process, simpler and more accessible project documentation. Modules can have multiple purposes and thus, a reduced number of components mean less machining and tooling. The fabrication process is shorter and the product cycle – design plus fabrication – is considerably reduced.

A reduced number of components determine a better material recovery because the product disassembly is easier and facilitated by the usual, universal assembling solutions. Simple assembling solutions are form assembling with less or no addition material. Standardized joining systems, whenever possible using the same materials as of the joined parts, self-fastening, and design solutions that permit disassembling and material selection, are suggestions that should be added to the above mentioned advantages of the modular constructions. Modular constructions exclude assembling solutions that need adhesives, glues, or similar, which might involve material mixing, like welding. Modern solutions can be adapted like thermoplastic hot-melt adhesives soften when heated, allowing the separation of substrates. Cooling can also be used to facilitate mechanical breakdown in joints produced with adhesive systems that become brittle below their glass transition temperature [4] [6].

5. CASE STUDY: MODULAR FURNITURE

Modern trends in interior design are towards leaving lots of open space inside the rooms, especially for the living rooms. Companies producing furniture need to fulfil these needs and adapts their designs to this trend. Young people usually have small apartments and need furniture to fit to all their needs. This is the reason why they would prefer folding or retractable furniture that can provide more space when necessary. They also look for suspended furniture that uses more of the available space.

The best solution for this category of users, and not only, is modular furniture that can be easily inter-changed or transformed. Visually it is a better solution than suspended one, and definitely it is more robust and resistant than the foldable type.

The object in Figure 3 is a multifunctional product, based on a modular concept.

Fig. 3 Modular furniture. [8]

The modular construction permits changing the configuration according to necessities. The minimal configuration is a simple sofa with 2 places and a table between. From the structure can be extracted a table and two additional chairs, extending the number of sitting places to five plus a table. In this simple way the same space can accommodate a small group of friends having a party or a simple evening chat.

Obviously, other configurations are possibly, using the existing modules. One can buy and build a simpler configuration consisting in the table and the two chairs, or only the sofa, with, or without the table. The space occupied under the sofa by the soft parts of the chairs can be replaced by drawers, giving an extra storage space.

Modules are produced separately and sold separately, according to the customer needs thus production is not disturbed by the modular design.

6. CONCLUSIONS

Building modular products is highly recommended because of many advantages these structures have. The solution ensures a minimum number of parts and several variants in which the product can be presented to the customer, for a unique design. The variants can be obtained either as a design output, or as a different assembling scheme. It should facilitate the product repair and upgrading. The modules can be produced, and tested before reassembling. This might result in a wider variety of products, in a larger range satisfying more customers belonging to different target groups. Standard modules can be designed and produced as spare parts.

However, the modular solution should be adopted from the early stages of the design process, in the conceptual design stage, when, starting from the general function, the functional modules should be identified. That is the optimal stage when the modular thinking should be implemented.

REFERENCES

[1] Bârsan, L., Bârsan, A. (2010). *Conceptual Ecodesign for the Product Using Stage*. Published in RECENT journal, Vol.11, Nr.3 (30), Oct-Nov. 2010, pp.160-165. ISSN 1582-0246

[2] Bârsan, L., Bârsan, A. (2013). *Methodology for Reducing the Product Environmental Impact from the Early Phases of the Design Process*. Buletinul Stiintific al Universitatii „Politehnica” din Timisoara. Transactions on Hydrotechnics. Tom 57(71), Fascicola 1. ISSN 1224-6042.

[3] Bârsan, L., Bârsan, A. (2011). *Ecodesign Methodology Applied in the Product Conceptual* Design Stage. In: Proceedings of the 15-th International Conference „Modern Technologies, Quality and Innovation” ModTech 2011, Iasi-Chisinau 20-22 mai 2011, Vol.I , Pp.107-110. ISSN 2069-6736

[4] Bârsan, L., Barsan, A., Bolos, C. (2007). *Design for disassembly as an essential step in fulfilling the Ecodesign goals: Reuse, Repair, Remanufacture, Recycle*. In: Proceedings of the 2-nd International Conference on Engineering Graphics and Design. 7-10 of June 2007, Galati Romania. Pp 245-248. ISBN 978-973-667-252-1

[5] Bârsan, L., Bârsan, A. (2002). *Despre module şi modulare în designul industrial.* Simpozionul naţional cu participare internaţională PRASIC 2002, Vol.III, 7-8 noiembrie 2002, Braşov, p.119-122. ISBN 973-635-076-2

[6] Bârsan, L., Bârsan, A., Bolos, C., Lates, M. (2009). *Ecodesign in the Context of Sustainable Development.* Transilvania University Publisher, Brasov. ISBN 978-973-598-619-3.

[7] Bârsan, A., Bârsan, L. (2004). *Fundamentals of Product Design.* Transilvania University Publisher Braşov. ISBN 973-635-362-1.

[8] www.designrulz.com. Accessed 09.2015

Authors:

Prof. Dr. Eng. Lucian BÂRSAN, University Transilvania of Brasov, Department of Product Design, Mechatronics and Environment, E-mail: lbarsan@unitbv.ro

Prof. Dr. Eng. Anca BÂRSAN, University Transilvania of Brasov, Department of Product Design, Mechatronics and Environment, E-mail: abarsan@unitbv.ro.