World Conference: TRIZ FUTURE, TF 2011-2014

Product Architecture definition: evaluating the potentiality of TRIZ tools

Lorenzo Fiorineschi[a*], Francesco Saverio Frillici[a], Paolo Rissone[a], Gaetano Cascini[b]

[a]University of Florence, Dipartimento di Meccanica e Tecnologie Industriali, Italy
[b]Politecnico di Milano, Dipartimento di Meccanica, Italy

Abstract

Product Architecture definition plays more and more a crucial role for enhancing product customizability, easing after-sale management and reducing manufacturing costs. Despite major efforts have been dedicated to the development of methods and tools supporting Product Architecture definition for "Adaptive Design" tasks, no real means are available while addressing more radical innovation activities. The paper proposes a critical overview of TRIZ models and tools to evaluate their potential integration into a comprehensive methodology for Product Architecture definition. A comparison with the three major modularity methods is performed with the aim to establish how TRIZ can be located thereupon to current state of the art of Product Architecture management. An academic case study is discussed, in order to show how the OTSM Network of Problems approach can bring a significant contribution in that sense.
© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC

Keywords: TRIZ, Modularity, Product Architecture, Original Design;

1. Introduction

The definition of Product Architecture is based on the distinction made by Ulrich and Eppinger [1] between functional elements and physical elements:

- Functional elements are individual operations and transformations that contribute to the overall performance of the product.
- Physical elements of a product are parts, components or sub-assemblies that implement the product's functions.

Pahl and Beitz [2] define Product Architecture as the scheme showing the relationship between function structure of a product and its physical configuration; a graphical representation of this definition is showed in figure

1. Another well acknowledged and almost equivalent definition has been provided by Ulrich and Eppinger in [1], where Product Architecture is defined as the scheme by which each function of a product is allocated into physical components.
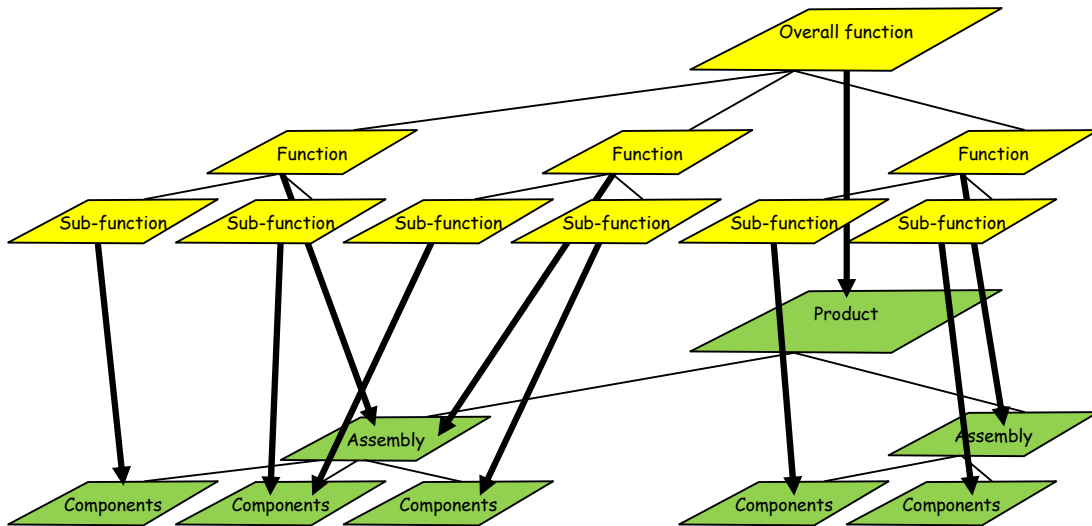

Fig. 1. Product Architecture in terms of functional elements and physical elements [2].

The management of Product Architecture requirements and constraints is a crucial issue in product and process development, as confirmed by the considerable amount of studies which have been performed in the last two decades, especially with the aim of developing methodological approaches to assist the grouping of product's components into modules [3]. The interest of scholars towards such specific research target, is motivated by the common assumption that the "modularization" of products can give rise to benefits under many points of view [4], e.g. reduction of life cycle costs, increased upgradability, customizability and reusability, etc. Indeed, in recent researches, the question regarding which is the optimal degree of product Modularity [5] has been investigated.

These research efforts have brought to the development of several methodologies to support the tasks of Product Modularization, which tackle the problem from several perspectives and consider different criteria to measure modularity [6] each of them with different characteristics, but substantially with the same purpose, i.e. the re-design of existent products in order to reach a higher degree of modularity.

A careful analysis of the literature in the field has revealed that three main approaches can be considered as the most representative, since they are well established in academia and successfully tested through industrial case studies: a short introduction to these methods is reported in the next section.

A critical discussion of the main characteristics of the existing methods supporting Product Modularization is the basis of this paper to define a list of descriptors which aim at characterizing an ideal method for Product Architecture definition, capable to preserve current capabilities and to overcome existing lacks, especially related to the Concept Design phase of new product development.

In such context, TRIZ body of knowledge is investigated in order to assess the potentiality and applicability of problem solving tools for supporting Product Architecture definition activities. They will be compared with considered modularity methods, validating extracted considerations in a qualitative manner.

After the state of the art analysis on product modularity methods discussed in section 2, section 3 is dedicated to the comparison with some models and tools of the TRIZ body of knowledge. In section 4 the results listed in the previous section are discussed in detail through an example application and finally, section 5 reports conclusions and future developments.

2. Product Modularity methods: State of the art

As reported in [8], the Design Structure Matrix (DSM) (e.g. in [9]), the Modular Function Deployment (MFD) [10] and the Function Structure Heuristics methods (FSH) [11], can be considered as a representative sample of existent methodologies for Product Modularization. This is confirmed also by [12], where the same sample is identified as the major modularization methods.

Many authors (e.g. [1], [13], [14], [15]) recognize Steward [16] as the first developer of the Design Structure Matrix (DSM) thanks to his work dated 1981, where this type of matrix representation was used for the analysis of design descriptions [1], i.e. descriptions which have the purpose of transferring information about the designed artifact. During the years, different applications of the DSM have been developed, for instance Eppinger et al. [17] use it to study interdependence between product development activities, while Pimmler and Eppinger [9] develop a special form of DSM in order to manage Spatial, Material, Energy and Information interaction between functions or physical components. Moreover Sosa et al. [18] use the DSM to study how the product architecture impacts on Design Team interactions.

The DSM tool can be subdivided in four main types [15], whose distinction is based on the type of dependency that is represented. The first matrix typology, the so called Component-based DSM, is used to manage the Modularization of products thanks to its capability to reorganize the architecture by using matrix manipulation algorithms which however, according to [8], are for the binary DSM where the interactions between elements are not separated into the four previously mentioned categories introduced in [9].

The method of Function Structure Heuristics (FSH) has been developed by Robert B. Stone in 1997 [19], where he reports his definition of working heuristics: "a method of examination in which the designer uses a set of steps, empirical in nature, yet proven scientifically valid, to identify modules in a design problem." The starting point of the method is a general functional structure of the system, which, as already mentioned in [8], is based on the Pahl and Beitz model [1]. Even though the method originally adopts a functional basis, as remarked by Stone, it can be employed also without using it. Then, three heuristics have been developed in order to find modules operating on the functional structure of the product [11] [19].

According to Hölttä [8], this method just brings to modularity suggestions, while the direct intervention of the designer is required in order to choose which module should be implemented. A rule suggested by Stone [19], is to implement the module with the smallest number of sub-functions. Many developments of the method have been proposed during the years, e.g., Fixon [13] reports that efforts have been done in order to include product family considerations, while Gershenson in his review [6] states that a widening of the work concerned the portfolio architecting.

The Modular Function Deployment method (MFD) is well described in [20], where also some examples are reported in order to help the comprehension. A short description is here reported with the aim to introduce how the method works and what are his most important features.

Modular Function Deployment is defined by Erixon and Ericsson [20] as a structured method developed to find the optimal modular product design, taking into considerations company's specific needs. It is composed by five steps, i.e., "define customer requirements", "select technical solutions", "generate module concepts", "evaluate module concepts" and finally, "improve each module". In the first step, a simplified version of the Quality Function Deployment method (QFD) is used to link customer needs to product properties; then, in step two, functions are identified and corresponding technical solutions are selected. In step three the previously selected technical solutions are investigated so as to evaluate their possibility to form a module; for this purpose the so called "Module Drivers" and the Module Indication Matrix (MIM) are introduced. The last two steps are dedicated respectively to the generation of module concepts and to the preparation of technical document to be used for the improvement of modules.

Due to the fact that most of the DSM modular design methods are used to group physical components into modules by clustering the matrix, according to [12] they cannot be used in early phases of design, because of the lack of information about the structure; MFD method is a powerful tool that allows to consider a variety of modularization scopes, namely Module Drivers, during the development of the modular product, but without any instrument or guideline to be used in early phases of concept definition of a new product, e.g. the choice of

working principles to adopt. Finally, FSH method is based on function structure definition of Pahl & Beitz [2], and it uses different heuristics in order to form modules from product's function structure, but, for example, there is a lack in managing multi domain product requirements.

Recovering the definition of "Adaptive Design" and "Original Design" [1], the totality of current methods have been successfully tested for case studies belonging to the first type, but there is a lack of attempts in managing the problem of Modularity during the conceptual phase of a completely new product, where both function structures and working structures are completely unknown. In fact, as showed in [12], no one of the considered methods is currently used for New Product Development.

3. TRIZ support to modularity in New Product Development activities

Beyond the identification of the methodological lacks to be addressed, the state of the art analysis overviewed in the previous section allowed also to identify the features characterizing an ideal methodology for Product Modularity. More specifically, each work has been analyzed so as to extract comments and descriptions reported by the authors about what is desired to support Product Modularity.

All these characteristics have been resumed in nine "descriptors", lately used as a term of comparison with TRIZ concepts and models.

3.1. Building a list of Describers of a methodology for Product Modularity

The publications related to the three selected methodologies (DSM, MFD, FSH) have been analyzed searching for most relevant features formalized according to the Element Name Value model (ENV) [7], where the "Element" refers to the investigated method, the "Name" refers to the descriptor and the "Value" is expressed in term of "positive value" (TRUE) and "negative value" (FALSE) . Figure 2 shows an example of the application of the model to FSH methodology.

As a whole, seven describers have been extracted by combining the desired features of the three methodologies; in addition, two more descriptors have been proposed by the authors in order to address two issues still not discussed in literature:

- Capability to support the definition of the physical structure of a new product.
- Product Architecture definition in case of radically new products.
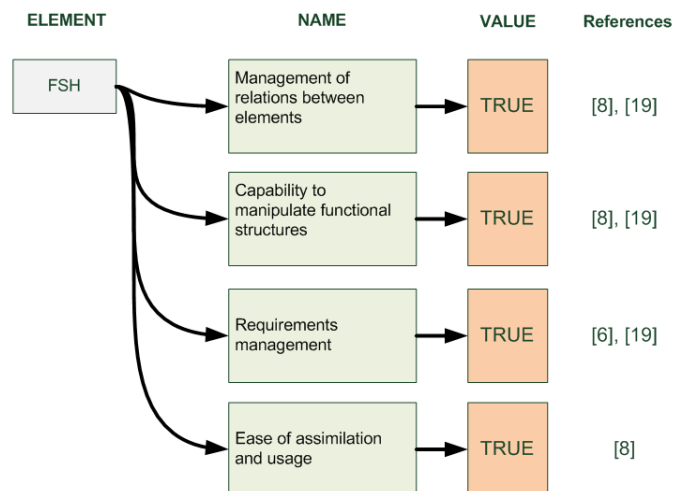

Fig. 2.Most relevant features of a Product Modularity methodology described through an ENV model built upon the literature about FSH.

The resulting list of descriptors is reported below:

A. Management of relations between elements
B. Capability to manipulate physical structures
C. Capability to manipulate functional structures
D. Requirements management
E. Multi-domains management
F. Ease of assimilation and usage
G. Support in defining physical structures from the functional one
H. Usability in complex systems
I. Product Architecture management in Concept development for New Products

3.2. Descriptors of a methodology for Product Modularity

A brief description of the meaning of the descriptors is reported below:

A. Management of relations between elements:

For the aim of this work, both functional and physical elements [1] should be taken into consideration; moreover, a comprehensive methodology should allow mapping energy, material, information and spatial relationships among the elements.

It is worth highlighting that it is possible to further distinguish these relationships between direct relations, as for example a flow of material between two functional elements, and indirect ones, as for example a flow of material between two physical components, which in fact can be thought as a the result of a direct interaction between functions delivered by the physical components (figure 3).
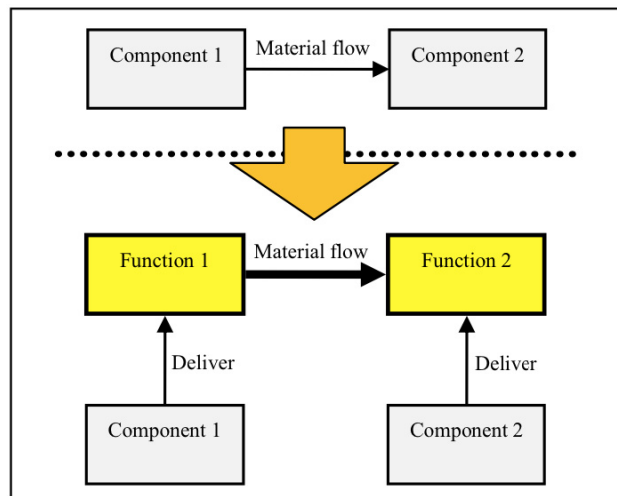

Fig. 3. Schematic representation of indirect relationship between two physical components.

A negative value of this descriptor means that the considered method or tool has a poor capability to keep in consideration the relations among elements during the design process.

B. Capability to manipulate physical structures:

It is intended as the capability of the method to support systematic modifications of the physical structure of the product so as to fulfill a set of requirements. A positive value of this descriptor means that the method allows manipulating the physical structure of the product in order to achieve a certain design objective.

C. Capability to manipulate functional structures:

Similarly to the previous descriptor, it refers to the capability of the method to systematically apply modifications to the functional structure of the product in order to fulfill a set of requirements. A negative value of the descriptor means that the considered method cannot operate in terms of functional elements.

D. Requirements management:

It is intended as the property of the method to properly keep into consideration complex sets of requirements during the design process. A negative value means that the considered subject operates independently on the requirements list.

E. Multi-domains management:

Considering the definition of domain reported in [21], i.e. "a specific perspective of the system", this descriptor is intended as the capability of the method to consider different perspectives of the system during the design process. A negative value means that up to two or three domains can be considered by the subject, while a positive value indicates that an undefined number of domains can be considered.

F. Ease of assimilation and usage:

It is meant as the amount of required knowledge of the user in order to use the tool or the method. A negative value stands, for example, for a method that needs the use of many different tools in its steps, while a positive value means that the user has only to learn method's instructions, without the necessity to use other external tools.

G. Support in defining physical structures from the functional one:

This descriptor represents the capability of the method to guide the user in the translation of the functional structure into the best physical one. A negative value means that this is not possible for the considered subject.

H. Usability in complex systems:

A method capable to support the management of systems characterized by a high number of elements and parameters to be kept under observation (requirements, constraints, etc.) is assumed as suitable to address complex system. A positive value indicates that the considered method allows mapping complex situations.

I. Product Architecture management in Concept development for New Products:

Assuming the definition of Product Architecture by Ulrich [1], the descriptor represents the capability to manage functional elements, physical elements and their relationships during the process of the concept development of a new product, where initially nothing is known about it. A negative value means that this task is not supported by the considered method.

3.3. Comparing Product Modularity methods with TRIZ

The descriptors identified in the previous section allow to make a systematic comparison between the selected Product Modularity methodologies and to discuss the potential contribution of some TRIZ models in this specific domain. The results of the comparison are showed in table 1, where evaluations are expressed only in terms of positive values (TRUE) or negative values (FALSE). Moreover, With the aim of evaluating the potentiality of TRIZ tools in the management of Product Architecture issues, an analysis of them has been performed taking into consideration the same describers. Results are exposed in table 1 where furthermore, in the right column, the specific considered tool or a brief justification of the given evaluation is indicated. By observing the table and focusing the attention on Product Modularity methods, it is evident that descriptors A to E are properly addressed by state of the art methodologies, while evident lacks appear for the last four descriptors. Concerning TRIZ, a detailed explanation of what has been stated is reported in the following chapter, but it is worth anticipating that it appears advantageous also with respect to some features missing in other available methods.

Table 1. ENV Model results of the Modularity methods and comparison with TRIZ body of knowledge.

	Descriptors	Modularity Methods			TRIZ	Comments
		DSM	FSH	MFD		
A	Management of relations between elements	TRUE	TRUE	FALSE	TRUE	Functional model
B	Capability to manipulate physical structures	TRUE	FALSE	TRUE	TRUE	Functional model
C	Capability to manipulate functional structures	TRUE	TRUE	TRUE	TRUE	Functional model
D	Requirements management	TRUE	TRUE	TRUE	TRUE	Network of Problems (OTSM-TRIZ)
E	Multi-domains management	TRUE	FALSE	TRUE	TRUE	Hybrid Functional Model
F	Ease of assimilation and usage	FALSE	TRUE	FALSE	FALSE	TRIZ expert and continuous feedbacks from the subject meta-expert are needed
G	Support in defining physical structures from the functional one	FALSE	FALSE	FALSE	PARTIAL	Pointers to Effects , System Operator
H	Usability in complex systems	TRUE	FALSE	FALSE	TRUE	Problem Flow Network (OTSM-TRIZ)
I	Product Architecture management in Concept development for New Products	FALSE	FALSE	FALSE	TRUE	Network of Problems (OTSM-TRIZ)

4. Discussion of results

A question that might arise observing the table 1 refers to the possibility of an integration between specific elements of the TRIZ body of knowledge and the selected Modularity methods, in order to increase the efficiency of both. For example, it is possible to investigate about how the Functional model of TRIZ can be implemented in the MFD method so as to allow its potential to manage relations between the functional elements. In fact, observing the

step 2 of the considered method [20], where the functional structure of the product is visualized together with the selected technical solutions, the introduction of the TRIZ functional modeling could result very helpful. Similarly, the functional model of TRIZ might be used in FSH in place of the Pahl and Beitz function structure, in order to manipulate the physical structure of the product. Besides, these integration opportunities need a more detailed investigation and test.

Still with respect to the results showed in table 1, it appear quite evident the complementarity of the scores relative to the descriptors E and F, where the FSH method is the only one with negative value for the first and the only one with positive value for the second, i.e. the ease of assimilation and usage.

Therefore, the question that might arise is the following: Since the FSH method, which is the more simple to assimilate is strongly based on heuristics, can they be used in order to simplify the learning process of the TRIZ elements suitable for architecture design, without losing the capability of managing multiple domains? This might be a further starting point for future investigations.

This chapter continues discussing in further details the results presented in table 1 concerning TRIZ support to Product Modularity development activities.

4.1. Descritpor "A": Management of relations between elements:

In classical TRIZ the interaction among system elements is represented by means of Substance-Field models, Substances being an abstract representation of an element actively or passively involved in an interaction allowed by the presence of a Field. The functional model of modern TRIZ is a formal representation of a triad Tool-Action-Object, where the Tool is the function carrier capable to impact at least one property of the Object as the effect of its Action. As such, a TRIZ functional model allows to see how the constituting elements of a system are functionally connected, explicitly representing both intended and undesired interactions.

A further typical distinction is made among elements of the system, namely subsystems, and elements beyond the system border, i.e. super-systems. A complete mapping of functional resources also highlights energy, material and information flows used or produced by the system.

The relationships that are traditionally considered in Product Architecture definition, as previously mentioned, can be of different types: spatial, material, energy or information/signal. Therefore, except for the spatial relationship, all of them can somehow be visualized in the functional model.

Furthermore, it is possible to directly manage the functional relationship between physical components, and thus to coherently represent the functional and the physical structure together; as such it can be considered as a valid candidate to be used for managing the entire product architecture.

4.2. Descriptor "B": Capability to manipulate physical structures

The functional model has been considered as a valid tool to be used also for manipulating the physical structure of a product thanks to its capability to visualize its components, as well as the possibility to change, add or delete any of them.

4.3. Descriptor "C": Capability to manipulate functional structures

Thanks to its capability of visualizing the functional connections among the elements of a system, the functional model is a valid tool able to intervene on the functional structure of a product. Still it is necessary to highlight a missing feature, i.e. the lack of a hierarchical organization of the functions which implies a practical limitations at distinguishing the different levels of detail of a Product Architecture.

4.4. Descriptor "D": Requirements management

Requirements management is a very important issue of product concept development. The Network of Problems [22] allows representing sets of requirements simultaneously in the form of problems to be addressed.

4.5. Descriptor "E": Multi-domains management

Hybrid Functional Model [23] is an extension of the above mentioned Functional model in which also boxes representing the underlying Evaluation Parameters are showed. Thus, it is possible to annotate if an active element of the system has positive or negative effect on object parameters, possibly belonging to different domains. Examples of possible domains are [24]: Physical components (parts), functions, processes, persons, stakeholder requirements, boundary conditions, parameters/attributes/features, etc.

4.6. Descriptor "F": Ease of assimilation and usage

The inventive potential of TRIZ-based problem solving is as well acknowledged as the steep of its learning curve. A typical industrial implementation model of TRIZ consists in the collaboration of a practitioner of the methodology with subject meta-experts, thus with regular interactions and information exchanges. As a consequence, this descriptor has been negatively evaluated with respect to other design methods.

4.7. Descriptor "G": Support in defining physical structures from the functional one

Despite a designer who has assimilated a TRIZ way of thinking is supposed to have a more effective attitude to the definition of a suitable physical structure of a system, starting from its functional architecture, TRIZ does not present instruments explicitly dedicated to this task. Nevertheless, the so called Pointer to Effects [25] helps performing the first steps of this process, i.e. the identification of the features of the physical element in charge of delivering the selected function. Further support is provided by the System Operator [23] with specific objective to identify resources to be leveraged for delivering the desired functions. As a whole, the evaluation of this descriptor is just partially satisfactory.

4.8. Descriptor "H": Usability in complex systems

OTSM-TRIZ (the Russian acronym for the General Theory of Powerful Thinking) is one of the modern directions of development of classical TRIZ, proposed by Altshuller himself since 1975 [22]. As claimed in [26], the purpose of OTSM is to provide systematic means to manage complex problems, by decomposing them into elementary problems, still keeping a holistic view of the entire design task.

4.9. Descriptor "I": Product Architecture management in Concept development for New Products

This is somehow the most important descriptor to be considered, since TRIZ seems to result winning whereas all other methods fail. In fact, due to their re-engineering nature, the considered Product Modularity methods are not able to manage Product Architecture problems during the concept development of a new product. Besides, OTSM-TRIZ Network of Problems seems to be a valid candidate to fulfill the requirements expressed by this descriptor: the case study reported below has been used as an opportunity to investigate this feature, by developing the problem net till a level of detail suitable to reveal also first sketches of structures implementing partial solutions.

The considered case is the development of a new "Handy paper sheets joiner" with the aim to find a new way of joining paper sheets capable to operate with different number of sheets with the same tool. Considered constraints and evaluation parameters are showed in table 2.

Table 2. Constraints and Evaluation Parameters for the new paper sheets joiner development.

Handy paper sheets joiner	
Constraints	Maximum dimension as the actual handy stapler
	Cheap construction materials
	No tooling operations to realize parts
	The height of pile of sheet has not to be sensibly increased by the joining system
Evaluation parameters	Low number of parts
	High range of number of sheets to be joined

The net has been realized considering as starting problem "How to join several sheets together?", then the definition of the different branches has be performed and the links among problems and partial solutions have been realized. Space limitations do not allow to report here the whole resulting network, but excerpts of it are showed and described in detail here below; furthermore, in table 3 the main characteristics of the resulting net are listed.

Table 3. Main characteristics of the Network of Problem developed for the case study.

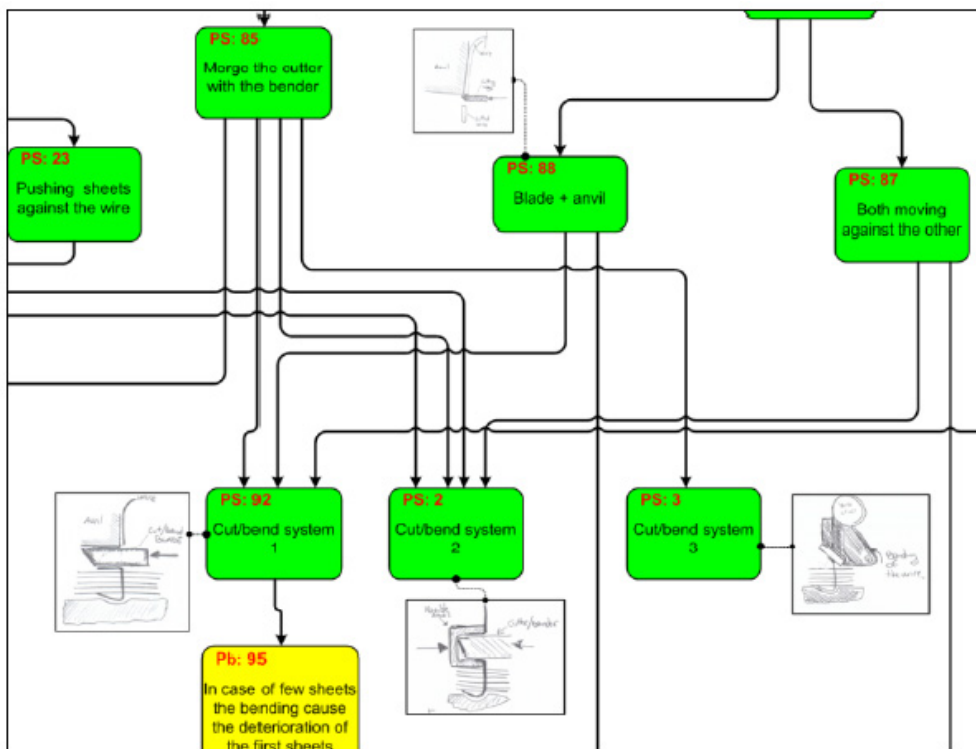|	
Number of main branches	4
Number of Problems (Pb)	51
Number of partial solutions (Ps)	72

Fig. 4. Excerpt of the N.O.P.. Different solutions of a problem could, when necessary, be visualized as preliminary structures.
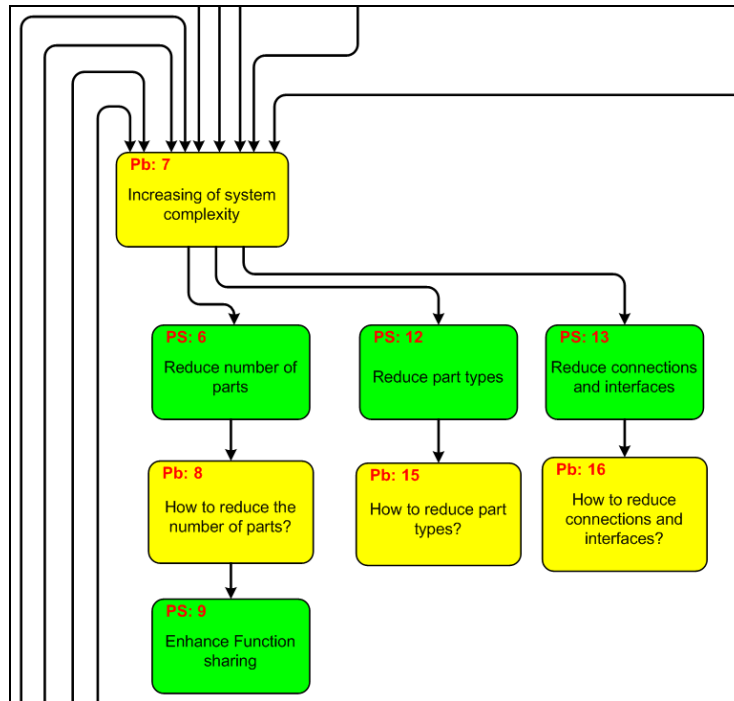
Fig. 5. Excerpt of the N.O.P.. As solutions are developed to a lower level of detail, classical problems of Product Architecture management arise.

Generating the net with the list of constraints and evaluation parameters of table 2 kept under consideration, can be considered a first positive sign in evaluating the potentiality of the tool. In fact, this list suggests the branches of the net from where to start the development of the analysis; moreover, many constraints and evaluation parameters are referred to the structure or to the process used to obtain the structure. Thus, the whole network can be recognized as a preliminary way of managing the architecture of the product.

Although in a disordered manner, with the NoP it is possible to manage the functional structure of the product for each level of detail. In fact, many of the problems which compose the net can be translated into functions or sub-functions of the product. The above mentioned "disorder" is meant as the fact that the latter kind of problems are mixed into the net together with the overall set of problems and then, when the network become quite big, it might be onerous to extract functions and the relative functional structure for each solution.

The NoP is characterized also by another useful characteristic, i.e. the possibility to represent different solutions (e.g. in terms of structures) as showed in figure 1, thus facilitating their comparison and also to derive different physical structures from each functional architecture.

Furthermore, as for instance represented in figure 2, the level of detail of the analysis can be developed until classical problems which characterize the architecture of a product may arise.

So, recalling the definition of Product Architecture by Ulrich [2], the Network of Problems has the potential to manage most of its needs in terms of how functions are implemented in physical components, but, at the state of the art, this is still not feasible in a direct manner.

In terms of Design Team management, the NoP can be a useful tool to distribute the workload among the available human resources, so as to develop different concepts with a concurrent approach and/or to work on subassemblies or parts implementing functions at different levels of detail. In the specific case study of the sheet joiner system, two of the three macro-branches have been developed simultaneously, i.e., the "Compression force" and the "Physical constraint" branches. Because of the necessity of experimental trials in order to further develop the first branch, the involved designer has stopped at a more abstract level of concretization, while the second designer has continued the development of the other branches by enriching the net with a series of sub-branches, some of

them regarding the study of solutions for problems involving different parts of the system. Once the preferred branch has been identified, two potential solutions have been analyzed in details and the design team has been split again in order to develop the two concepts in a concurrent way.

Thanks to these hierarchical distribution of resources, a preliminary concept of the system has been obtained without the need of review iterations. Instead, if the same design activity was approached without the NoP, the number of the needed iterations would be related to the type of the solution chosen for the development. In fact, one of the advantages of the net is that problems belonging to different level of abstraction and/or detail can be linked together, allowing the designer to know if the selected solution is prosecutable or not, without bring the solution at lower levels of detail. It follows that with the NoP approach, a sensitive increase of the efficiency of the design process has been reached.

5. Conclusion and future developments

The present study aims at investigating the potential contribution of TRIZ for Product Architecture management, with a specific focus on the support of conceptual design for new product development. In fact, managing Product Architecture since early phases of an original design concept might be a valid strategy to reduce the number iterative steps actually needed in order to obtain the final configuration, but the state of the art doesn't allow it for the moment.

A systematic comparison of the three major Product Modularity methods has brought to the identification of a set of reference descriptors for an ideal methodology in this area of design. These descriptors have been analyzed within the perspective of the classical and modern TRIZ body of knowledge, so as to identify suitable models and tools to address each specific desired feature.

Furthermore, as a consequence of the comparison, a mutual integration between TRIZ tools and current Modularity methods has been speculated, with the aim of propose future investigations about the possibility to share those positive characteristics. Particularly, the possibility to implement the Functional Model in FSH and MFD methods have been speculated and the question regarding the possibility to use heuristics in order to simplify the learning procedure of TRIZ has been placed.

In conclusion, it is possible to assert that TRIZ seems to have a relevant potential of being used for Product Architecture management, also where other dedicated Product Modularity methods fail.

Furthermore, thanks to results obtained in the case study adopted for this article, is possible to assert that the use of the NoP allow a practical management of the design team, which is an issue often considered in the literature.

Obviously, this is only a first step of an investigation aimed at building a comprehensive methodology capable to fulfill all the relevant descriptors proposed in this paper. Moreover, this work considers each descriptor in a distinctive and transversal manner, while the management of Product Architecture problems is characterized by all of them simultaneously.

References

[1]   K. T. Ulrich, S. D. Eppinger, Product Design and Development. McGraw-Hill. 5th edition. 2003. ISBN 0-072-47146-8.

[2] G. Pahl, W. Beitz. Engineering Design. 2nd ed. Springer-Verlag, London Ltd. 1999. ISBN 3-540-19917-9.

[3]   S.K. Fixson. Modularity and Commonality Research: Past Developments and Future Opportunities, Concurrent Engineering June 2007 15: 85-111

[4]   J. K. Gershenson, G. J. Prasad, Y. Zhang (2003). Product modularity: Definitions and benefits, Journal of Engineering Design, 14:3, 295-313

[5]   A. K. W. Lau, R. C. M. Yam, E. Tang. The Impact of Product Modularity on New Product Performance: Mediation by Product Innovativeness, Journal of Product Innovation Management 2011;28:270–284

[6] J. K. Gershenson, G. J. Prasad, Y. Zhang (2004). Product modularity: measures and design methods, Journal of engineering Design, 15:1, 33-51

[7] D.Cavallucci, N. Khomenko. From TRIZ to OTSM-TRIZ. Addressing complexity challenges in inventive design, International Journal of Product Development, Volume 4, Number 1-2/2007, Pages 4-21

[8] K. Hölttä-Otto (2005). Modular Product Platform Design, Doctoral Dissertation, Helsinki University of Technology - Department of Mechanical Engineering, Machine Design - ISBN 951-22-7766-2.

[9] T.U. Pimmler, S.D. Eppinger. Integration analysis of product decompositions, In Proceedings of ASME Design Engineering Technical Conferences, 6th International Conference on Design Theory and Methodology. Minneapolis, MN. 1994.

[10] A. Ericsson, G. Erixon. Controlling Design Variants. Modular Product Platform, Copyright 1999 by Modular Management AB and Society of Manufacturing Engineers, ISBN 0-87236-514-7

[11] R.B. Stone, K. L. Wood, R. H. Crawford. A heuristic method for identifying modules for product architectures, Design Studies, Volume 21, Issue 1, January 2000, Pages 5-31

[12] C.Daniilidis, V. Enßlin, K. Eben, U. Lindeman. A Classification Framework for Product Modularization Methods, International Conference on Engineering Design, ICED1, 15 - 18 August 2011, Technical University of Denmark

[13] S. K. Fixson. The Multiple Faces of Modularity , A Literature Analysis of a Product Concept for Assembled Hardware Products, Technical Report 03-05 June 2003, University of Michigan Industrial and Operations Engineering 1205 Beal Avenue Ann Arbor, MI 48109

[14] M. E. Sosa, S. D. Eppinger, C. M. Rowles. A Network Approach to Define Modularity of Components in Complex Products, Journal of Mechanical Design - November 2007 - Volume 129, Issue 11, 1118

[15] A. K. Kamrani, S. M. Salhieh. Product Design for Modularity second edition, 2002 - Kluwer Academic Publishers, ISBN 1-4020-7073-X

[16] D.V Steward.The design structure system: A method for managing the design of complex systems, IEEE Transactions on Engineering Management, 1981, Vol. 28, pp. 71–74

[17] S. D. Eppinger, D. E Whitney, R. P. Smith, D. A. Gebala. 1994. A Model-Based Method for Organizing Tasks in Product Development. Research in Engineering Design, vol.6, no. 1, pp. 1-13.

[18] M. E. Sosa, S. D. Eppinger, C. M Rowles. 2003. Identifying Modular and Integrative Systems and Their Impact on Design Team Interactions. ASME Journal of Mechanical Design , 125(2), pp. 240–252.

[19] R. B. Stone. Towards a Theory of Modular Design, Dissertation presented to the Faculty of the Graduate School of the University of Texas at Austin in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy The University Of Texas At Austin, December 1997.

[20] A. Ericsson, G. Erixon. Controlling Design Variants. Modular Product Platform, Copyright 1999 by Modular Management AB and Society of Manufacturing Engineers, ISBN 0-87236-514-7

[21] K. G. M. Eben, C. Daniilidis, U. Lindemann. Interrelating and Prioritising Requirements on Multiple Hierarchy Levels, International Design Conference - Design 2010, Dubrovnik - Croatia, May 17 - 20, 2010.

[22] N. Khomenko, R. De Guio, L. Lelait, I. Kaikov. A framework for OTSM TRIZ-based computer support to be used in complex problem management. International Journal of Computer Applications in Technology. November 2007, Vol 30, Issue ½

[23] G. Cascini, F. S. Frillici, J. Jangtschi, I. Kaikov, N. Khomenko. TRIZ, Theory of Inventive Problem Solving, Improve your problem solving skills. Education and Culture DG, Lifelong Learning Programme, TETRIS (Teaching TRIZ at School)

[24] W.Bauer, C. Daniilidis, U. Lindemann. Approach for a Modularization Driven System Definition using Multiple Domains, 13th International Dependency and Structure Modelling Conference, DSM'11 Cambridge, Massachusetts, USA, September 14 – 15, 2011

[25] G. S Altshuller. Creativity as an exact science: The Theory of the Solution of Inventive Problems: Gordon and Breach Science Publishers, 1984v

[26] L. Fiorineschi, F.S. Frillici, P. Rissone. A comparison of Classical TRIZ and OTSM-TRIZ in dealing with complex problems. Triz Future Conference 2011 – Systematically Innovating for Sustainable Competitiveness, ISBN number: 978-0-9551218-2-1, pp 103-112