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Systematic design through the integration of TRIZ and optimization tools

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Abstract

Marketing strategies are focusing on innovation as the key for being competitive; as a consequence, product development processes must be improved in order to have a link as close as possible between conceptual design and detailed design activities. Within this context, TRIZ and TRIZ-based methodologies and tools are still poorly integrated with product embodiment means: CAD/CAE systems are not suited for supporting the designer in the conceptual design phase and at the same time inventive/separation principles, standard solutions etc. can hardly be translated into a modification of a CAD model and the only opportunity is to restart the modeling process.
A small consortium of Italian Universities is analyzing the opportunity to use Design Optimization tools as a means for linking Computer-Aided Innovation (CAI) tools with Product Lifecycle Management (PLM) systems: www.kaemart.it/prosit.
Among the specific objectives of the project, this paper describes how to analyze TRIZ technical contradictions by means of Design Optimization tools, with the aim of translating them into physical contradictions. The suggestions provided by inventive/separation principles are therefore converted into a new Design Optimization problem for the development of a novel solution.

Keywords: Systematic design; TRIZ; Computer-aided innovation; Topological optimization; Shape optimization;

1. Introduction

Market competitiveness through innovation is the common strategy of developed countries, even if the concept of innovation is very often abused and misused. Certainly, in order to release novel and valuable products, a crucial aspect for a company is the efficiency of its product development cycle from the so-called fuzzy front end to the detailed design. In other terms companies have to implement not just means for generating new ideas with a

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systematic approach, but also an integrated environment where effective ideas are efficiently converted into products.

Computer applications play a relevant role for increasing the efficiency of the whole process, but up to now systematic innovation methodologies like TRIZ are still poorly integrated with product embodiment means [1]: CAD/CAE systems are not conceived for supporting the designer in conceptual design activities and at the same time the outputs of a TRIZ problem solving tool (e.g. inventive/separation principles, standard solutions etc.) can hardly be translated into a modification of a CAD model and the only opportunity is to restart the modeling process.

A few preliminary experiments to integrate TRIZ principles within CAD systems have been attempted with promising, but still not satisfactory, results [2, 3]. Besides, a small consortium of Italian Universities has started the PROSIT project (www.kaemart.it/prosit), "From Systematic Innovation to Integrated Product Development", with the aim of bridging systematic innovation practices and Computer-Aided Innovation (CAI) tools with Product Lifecycle Management (PLM) systems, by means of Design Optimization tools.

Innovation and optimization are usually conceived as conflicting activities; in this project topology and shape generation capabilities of modern design optimization technologies are adopted as a means to speed-up the embodiment of innovative concepts, but also as a way to support the designer in the analysis of conflicting requirements for an easier implementation of TRIZ tools. In this paper the use of Design Optimization tools is proposed for identifying the physical contradictions underlying a mechanical system, i.e. the generalized problem model according to traditional TRIZ theory; then, TRIZ general solutions (i.e. inventive/separation principles etc.) are converted in new optimization problems in order to implement a novel solution. Section 2 reports a brief overview of Design optimization tools; section 3 describes how the logic of ARIZ has been reproduced by means of these tools and the overall procedure is detailed. Section 4 shows an exemplary application while the conclusions are briefly presented in section 5.

2. Design optimization

Designing by optimization techniques means translating a design task into a mathematical problem with the following basic entities:

- An *objective function,* i.e. the performance of the system that the designer wants to reach or to improve.
- A set of *design variables*, i.e. the parameters of the system affecting the objective function.
- A set of *loading conditions* and *constraints* representing the requirements the system has to satisfy.

The optimization algorithm finds the value of the design variables which minimizes, maximizes, or, in general, "improves" the objective function while satisfying the constraints.

The use of computers for design optimization is rather common in several fields since 1980's; besides, during the last years new optimization tools have been developed to solve specific design problems [4]. In the followings the main features of these techniques will be summarized.

In a *shape optimization* process the outer boundary of the structure is modified according to the optimization task. The shape of the structure, modeled through the finite element method, is modified by the node locations: the optimization algorithm, according to the loads and boundary conditions applied to the FE model, changes the coordinates of the nodes which are defined as design variables. The result of the optimization cycle is a deformed geometry of the starting shape structure.

The *size optimization*, is a special type of parametrical optimization in which the design variables are represented by some properties of structural elements such as shell thickness, beam cross-sectional properties, spring stiffness, mass etc. During the optimization process these parameters are modified by the algorithm until the expected goal is reached.

Topology optimization is a technique that determines the optimal material distribution within a given design space, by modifying the apparent material density considered as a design variable. The design domain is subdivided into finite elements and the optimization algorithm alters the material distribution within the design space at each iteration, according to the objective and constraints defined by the user. The external surfaces defined as "functional" by the user, are kept out from the optimization process and considered as "frozen" areas by the algorithm.

Topography optimization is an advanced form of shape optimization in which a distribution of ribs and pattern reinforcements is generated on a specific design region. The approach in topography optimization is similar to the approach used in topology optimization, but shape variables (node coordinates) are used instead of density variables. The large number of shape variables allows the user to create any reinforcement pattern within the design domain.

Moreover manufacturing constraints may be set in order to take into account of the requirements related to the manufacturing process. Sliding planes and preferred draw directions may be imposed for molded, tooled and stamped parts as well as minimum or maximum size of the structural elements (i.e. ribs, wall thicknesses, etc.).

However, since the design process has multidisciplinary characteristics, improving one performance of a system may result in degrading another. This kind of conflicts cannot be solved using Design Optimization because these techniques are able to focus the design task only to one specific performance to be improved. More precisely, Design Optimization tools allow management of multiple goals just by defining complex objective functions where a weight must be assigned to each specific goal [5]. Thus, the best compromise solution is generated on the base of an initial assumption made by the designer about the relative importance of the requirements, without taking account of the reciprocal interactions.

3. The logic of ARIZ through design optimization tools

The typical tool TRIZ newcomers encounter is the Contradiction Matrix. Besides, the effectiveness of such a tool is limited for at least two basic reasons:

- The reliability of the matrix is influenced by the technical field of application, since it has been built with patents related to inventions of the 1950-70's.
- Very often, the identification of the most suitable parameters, among the classical 39, to describe a technical contradiction is hard due to their overlapping and fuzzy definitions.

More experienced practitioners learn the logic of ARIZ, the algorithm for inventive problem solving, that leads to the transformation of a technical contradiction into a physical contradiction, i.e. opposite requisites for a design parameter. Authors' experience reveals that such a transformation implies a certain "assimilation" of the methodology by the user. Besides the following step, i.e. the adoption of separation and inventive principles as solution triggers to overcome a well identified contradiction, is much easier.

Indeed, TRIZ requires a paradigm change to designers: from a traditional approach focused on the definition of the "optimal" solution, i.e. the best compromise among a set of even fuzzily identified conflicting requirements, to a process aimed at the identification of the conflicting design parameters, in order to generate solutions that overcome those conflicts. Such a paradigm shift is rather hard for technicians involved in architectural/layout design tasks, but it's even harder for designers operating in the following phases of the product cycle, i.e. when the shape of the "mechanical" parts must be defined.

While sitting in front of the screen of a CAD system, a strong inertia barrier is constituted by the CAD interface itself suited for modeling already conceived geometries, but too rigid for supporting the designer in the fuzzy front-end of the process.

Therefore, the cultural reluctance vs. changing the design approach from optimization to conflicts overcoming, combined with the design tools rigidity, constitutes a major limit to the introduction of systematic innovation methodologies in these design phases. Besides, as summarized in section 2, these days new design optimization tools are available and they are pretty close to actual designer's perspective, therefore representing a further push towards "design for compromise" practices.

Nevertheless, TRIZ teaches that the harm of the system is the best resource to be adopted for improving the ideality of the system itself. On the base of this suggestion the authors have developed the following procedure, further detailed in sections 3.1-3.3. It is assumed that there are two possible starting situations:

0a. Design of a brand-new component: the designer receives functional requirements and technical constraints; the expected output is a detailed geometry.

0b. Redesign of a component/sub-assembly: an already existing design should provide higher performances and/or new requirements must be satisfied (e.g. reduced energy losses, noise emission etc.).

1. Whatever the starting situation is, a set of specific design goals and constraints should be defined. The first step consists in defining a set of optimization problems, i.e. defining functional surfaces, available

volumes, loads and constraints acting on the system. Clearly, there are some differences between 0a) and 0b), since in the first case the designer has a greater freedom, while in the second the functional surfaces and the boundary conditions are inherited from the existing design.

2. If the optimization activities brings to satisfactory results the design task is accomplished; besides, if the optimization problems lead to contradictory solutions a conflict analysis has to be performed. More precisely, the results of the optimization activities are translated into a set of physical contradictions, therefore overcoming the main obstacle for non-TRIZ experts, that is identifying the core of the conflict.
3. The physical contradictions can be approached by means of the separation principles or by a transition to a super/subsystem. These design hints should trigger to the designer a direction for overcoming the existing trade-off. As a consequence, a new Design Optimization problem can be defined.

3.1. From technical contradictions to design optimization tasks

The task of defining one or more design optimization problems on the base of the design requirements is not complex since goals and constraints should be already identified.

Instead of trying to fit the description of a design problem into a pair of improving/worsening features, it is much easier to define the objective and the boundary conditions of an optimization problem. In Table 1, an exemplary list of external requirements is reported with the corresponding available optimization approaches.

External requirements	**Objective**	**Constraint**	**External requirements**	**Objective**	**Constraint**
Static stiffness	B, T, S, P	B, T, S, P	Surface pressure	S, P	S, P
Dynamic stiffness	B, T, S, P	-	Thermal flow (cond.)	T	-
Weight – Mass	B, T, S, P	B, T, S, P	Thermal flow (conv.)	S, P	S, P
Stress – Strength	S, P	S, P	Center of mass pos.	T	T
Size – Volume	T, B, S, P	B, T, S, P	Inertia properties	T	T
Draw direction / tool accessibility	-	B, T, S, (P)	Buckling	T, B, S	T, B, S

Table 1-exemplary list of external requirements and their representation in optimization tasks
B=Bead/Topography Opt., T=Topological Opt., S=Shape Opt., P=Parametrical Opt.

3.2. From design optimization tasks to physical contradictions

According to the design requirements one or more optimization problems have been defined. It is obvious that if the results of these analyses point to the same direction, the design task doesn't hide any conflict and a technical solution can be implemented easily.

Besides, it may happen that it is not possible to reach satisfactory results according to the following situations: *(i)* two or more optimization problems bring to opposite directions; *(ii)* a single optimization problem has been defined, but the algorithm doesn't meet the objective. In the first case, the designer has to analyze the results of the optimization tasks and list all the contradictory directions assigned to the optimization variables (e.g. the value of a dimension high and low, the direction of a rib, presence/absence of material in a certain region etc.). In the second case the contradiction must be searched between the objective and one or more constraints: thus it is suggested to define a new set of optimization problems where the objective is kept constant, while the constraints are deleted alternatively. After such an analysis the contradiction should be defined in the form: "the geometry should be … in order to respect the constraint … and should not be … in order to reach the objective …".

3.3. From physical contradictions to a new design task

The identification of a physical contradiction brings from a conflict between external requirements to one or more "internal" design parameters with contradictory definitions. Such a paradox can be systematically approached according to classical TRIZ tools:

1. identifying the operational zone (i.e. the region where the contradiction occurs), the operational time (i.e. the interval where the contradiction occurs);
2. check if the contradictory requirements for the design parameter co-exist in the whole operational zone (separation in space), operational time (separation in time);
3. check if those contradictory requirements co-exist under any condition (separation on condition);
4. evaluate the opportunity to overcome the contradiction by means of a transition to the system components (sub-systems) or to its environment (super-system).

All these suggestions can be enriched by means of the guidelines provided by the inventive principles that can be associated to each separation principle. As a result, the designer should be able to define a new set of optimization problems according to the following exemplary list of actions: separating and/or segmenting the functional surfaces; dynamizing an assembly in order to have a different mechanical behavior under different operating conditions; moving to another dimension etc. (a complete list of suggestions is not compatible with the available space).

4. Exemplary application of the proposed approach

In order to clarify the whole process described in section 3, its basic (but not trivial) application to a sheet metal snips is here reported. Snips are hand shears used in cutting sheet metal, usually up to 0,5 mm thick. The typical layout of a pair of snips is exactly the same of common scissors, even if with appropriate dimensions.

Among the requirements sheet metal snips have to satisfy, it is worth to highlight: minimal force requested to the user, maximum length of cut at each operation (as design objectives) and light weight, limited overall size according to ergonomics, limited width for reducing sheet deformation (as design constraints).

According to this problem situation two initial optimization problems can be defined (omitted for space limitations); as a result two opposite directions are suggested: the shear length should be small in order to maximize the lever arm (minimize the requested effort), but the shear length should be high in order to cut a long piece of metal with just one operation. Such a physical contradiction can be overcome by means of a separation in time (e.g. with a ratchet mechanism) or by a separation in space (e.g. separating the lever arm, i.e. the distance between the shear edge and the fulcrum, from the shear length).

The last guideline led the authors to two conceptual solutions:

- moving to another dimension, i.e. designing the snips with a shear edge orthogonal to the lever arm;
- increasing the curvature of the edge, i.e. building a circular blade like a can opener.

An exemplary embodiment of the first concept is shown in figure 1 (right), obtained at the end of a second optimization problem where the functional surfaces have been defined according to the separation in space/another dimension principle (figure 1, left).

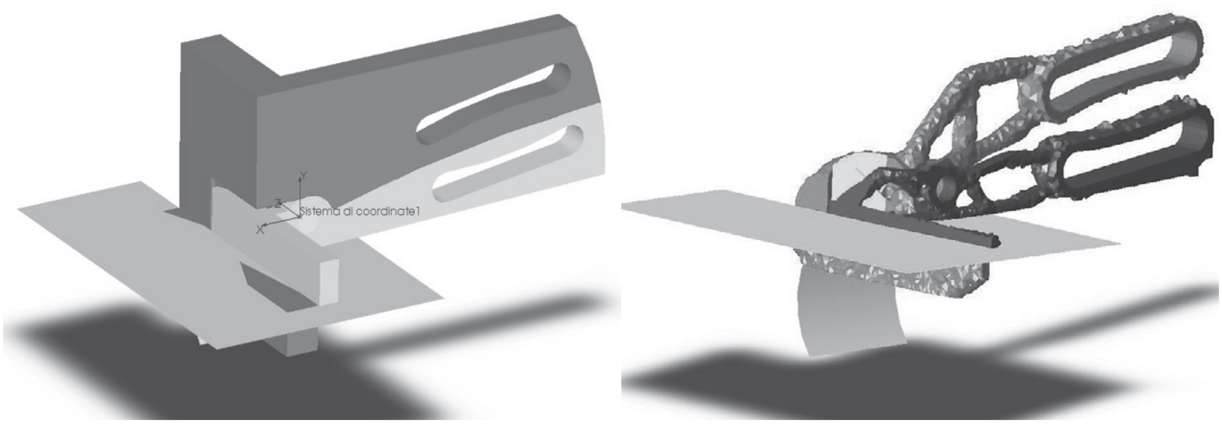

Fig. 1-Design space of a redefined optimization task (left); optimized design of a sheet metal snips (right).

5. Conclusions

In this paper, the adoption of Design Optimization tools as a means for bridging systematic innovation methods with CAD systems has been presented: the proposed procedure fits with the standard approach to design, but at the same time leads systematically to the identification of conflicting design parameters, thus overcoming the major difficulty of newcomers to TRIZ, i.e. the capability to describe design problems in terms of physical contradictions related to design parameters and not just conflicting (external) requirements.

Due to the space constraints of the manuscript just an exemplary application of the procedure has been shown to demonstrate the validity of the proposed approach. For the same reasons, some details about the definition of the optimization problems as well as the translation of the separation principle into a novel optimization problem have been omitted. During the oral presentation at the conference further details and examples will be presented.

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