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SUPPORTING SYSTEMATIC CONCEPTUAL DESIGN WITH TRIZ

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Abstract
Most acknowledged systematic conceptual design (SCD) methods are based on Functional Decomposition and Morphology (FDM). However, since some of the observed FDM flaws concern a non-comprehensive support to creativity, some scholars attempted to fill this gap by integrating FDM with the TRIZ body of knowledge. Unfortunately, non-negligible issues arise in these cases, hindering a comprehensive exploitation of TRIZ in SCD. This paper proposes an alternative way for exploiting the TRIZ potentialities within SCD, and three academic application examples are reported to show how the proposal works.

Keywords: TRIZ, design methods, engineering design, problem solving, conceptual design

1. Introduction
Engineering design activities constitute critical steps for the achievement of product success, because are directly affecting all the subsequent life cycle phases. Accordingly, the design process has been deeply investigated in the last decades, and the outcomes of these valuable efforts led to a variety of contributions about design models and methods. Some of these contributions concern the first phase of the design process, where taken decisions are acknowledged to influence about 80% of product costs (Ullman, 2010). In this context, the well-known approach based on Functional Decomposition and Morphology (FDM) (Pahl et al., 2007) is one of the most taught in academia, and refers to a specific concept of "function" and function structures. However, although the recalled academic success, non-negligible flaws affect methods based on FDM, leading some scholars to argue about its actual potentialities, and also proposing variants or potential alternatives (Chakrabarti and Bligh, 2001; Kroll, 2013). Among the recalled flaws, a non-comprehensive support to the generation of innovative solutions has been pointed out as one of the most impacting one (Tomiyama et al., 2009). Aiming at overcoming this issue, some scholars suggested to exploit specific "creativity enhancer" methods and/or tools to support idea generation activities in systematic design processes. Among these suggestions, TRIZ (Altshuller, 1984) has been considered as a possible and valuable support to creativity in conceptual design (Eppinger and Ulrich, 2007; Ullman, 2010). Unfortunately, FDM and TRIZ are characterized by evident differences, which make difficult to mutually exploit each other in a simple and effective way. More precisely, FDM is an engineering design method based on a specific definition of "function", while TRIZ is a problem solving approach where the concept of function (even if different from the FDM one) still plays a crucial role, but the concept of “contradiction” is also extremely important. Nevertheless, literature acknowledges some contributions that suggest possible integrations between the two recalled approaches, substantially trying to take advantage from both TRIZ creativity tools and systematic conceptual design (SCD) processes. However, also these contributions present some criticalities that hinder an efficient application (Fiorineschi et al., 2018).

In such a context, the objectives of this paper is to highlight the criticalities affecting extant SCD-TRIZ integrations based on FDM, to discuss about them and to extract suggestions for comprehensively exploiting TRIZ in SCD "environments".
To show the mentioned contents, the paper is organized as it follows: in Section 2, a short introduction of the main peculiarities of FDM and TRIZ is reported, to highlight their main differences and the criticalities affecting their mutual integration. Then, Section 3 proposes an alternative way to exploit the benefits of both SCD and TRIZ, and three application examples are shown in Section 4. Then, Section 5 reports discussions about the presented proposal and shows some possible research hints on the argument. Eventually, Conclusions are reported.

2. Background

2.1. Short introduction to TRIZ

TRIZ is the Russian acronym for "Teoriya Resheniya Izobretatelskikh Zadach", i.e. the "theory of the resolution of inventive problems", originally developed by the Russian engineer Genrich Altshuller (Altshuller, 1984). The fundamentals of TRIZ substantially argue about how to solve thousands of different technical contradictions by means of a limited number of "Inventive Principles" (IPs). According to Orloff (2006) a contradiction "*is the model of a system conflict that puts incompatible requirements on functional properties of components that are in conflict*", and 40 IPs have been identified for their resolution (Altshuller, 1984).
Moreover, a specific definition of function is present in TRIZ, i.e. functions are actions between two components: the subject (the component providing the action), and the object (the component that receives the action) (Fey and Rivin, 2005; Gadd, 2011). The function is therefore considered as delivered by this set of three elements: subject (S), action (A) and object (O) (Figure 1), which is often called SAO triad (Gadd 2011).

Figure 1. The TRIZ subject-action-object triad

In particular, to deliver a function, the action "A" has to modify or preserve one or more parameters of the object "O" (Savransky, 2000; Gadd, 2011).
The actions of the SAO triad are often classified in TRIZ as useful, insufficient (or even excessive), and harmful, according to the effect they produce on the object (Gadd, 2011). More precisely:

- Useful actions/functions: are the ones that results in a positive (required) change or preservation of a value of a parameter of the object of the function;
- Insufficient (or excessive) actions/functions: are those that deliver a positive change or preservation of a value of a parameter of the object of the function, but the action is performed with fewer degree of performance than required (or the action is performed with too much effort or with the use of non-optimal amount of resources);
- Harmful actions/functions: are the ones that results in inacceptable change or inacceptable preservation of a value of a parameter or a state of another material object.

Accordingly, in problem solving activities, it is possible to classify problems into three categories:

- Subject-missing (SM) problems: when the subject of the SAO triad needs to be identified to implement the required function.
- Performance problems (PP): when the action is insufficiently (or excessively) performed
- Harmful effect problems (HE): when a subject performs an undesired action on a object.

Many TRIZ tools have been developed for supporting inventive problem solving, available for all the three categories of problems. Moreover, TRIZ led to a number of developments and/or alternatives like, CROST (Orloff, 2006), OTSM-TRIZ (Khomenko et al., 2007) and TOP-TRIZ (Royzen, 1999), which increase the number of available tools and interpretations. A long time to learn is sometimes associated to TRIZ (Malmqvist et al., 1996), and the presence of the mentioned new developments may even worsen the problem. Maybe as a consequence of this observation, some scholars have performed investigations on the actual use of TRIZ tools within industry (Moehrle, 2005; Ilevbare et al., 2013; Spreafico and Russo, 2016), substantially highlighting that only limited sets of the available tools are more frequently used.

2.2. Systematic conceptual design

With the terms "systematic design", scholars often refers to those theories and methods where abstraction, establishing function structure, searching for solution principles, combining solution principles, etc. constitute the fundamental steps of the design process (Le Masson and Weil, 2012). One of the most acknowledged version of the recalled methods is that of Pahl et al. (2007), which subdivides the design process into four phases, i.e. the clarification of the task, the conceptual design, the embodiment design and the detail design.

For the scope of this paper, we focus the attention on the conceptual design phase, where FDM currently constitutes the reference model for systematic approaches. FDM is strongly based on the concept of "functions", intended as actions capable to transform one or more Energy-Material-Signal (EMS) input flows into modified outputs (see Figure 2).

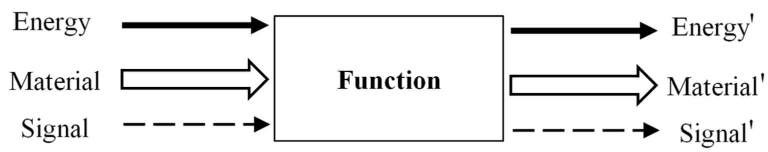

Figure 2. The EMS functional model

Function structures are obtained by connecting single functions each other, by means of input-output relationships characterizing the processed EMS flows (for example, the output flow of a first function constitutes the input flow of a second one, whose output flows are the input ones of one or more subsequent functions, and so on). Functions used in function structures constitute the rows of the morphological charts (Pahl et al., 2007), while columns contain representations of the different solution variants proposed to implement each function. In this way, different combinations can be evaluated, within the variety of solutions (working principles), then leading to the systematic generation of different concept variants to be evaluated and selected.

Although SCD approaches (most of them based on FDM) are widely taught in academia, unfortunately industrial practitioners rarely follow FDM, even where the systematic approach is traditionally diffused (Maurer and Widmann, 2012). Indeed, the industrial diffusion of academic design methods is a common issue, whose causes have been deeply investigated by scholars (Birkhofer and Kloberdanz, 2005; Geis et al., 2008; Jagtap et al., 2014), but it still constitutes an open research question. Additionally, generating functional descriptions can leads to several difficulties, also because of the presence of many different interpretations of the term "function" (Eisenbart et al., 2013; Vermaas and Eckert, 2013).

Moreover, frequent objections to the systematic approach concern a limited support to creativity (Birkhofer, 2011) because, as inferred by Leenders et al. (2007), an excessive use of the functional decomposition limits designer’s freedom and consequently limits her/his creativity.

2.3. TRIZ-FDM integrations and related criticalities

Pahl et al. (2007) suggested several methods for supporting the generation of creative solutions (e.g. Brainstorming, 6-3-5, Synectics, etc.), while TRIZ is considered as potentially valid support in other design textbooks (Eppinger and Ulrich, 2007; Ullman, 2010). Focusing the attention on TRIZ, Fiorineschi et al. (2018) recently identified and discussed the ten TRIZ/FDM integration proposals currently available in literature, identifying five general issues affecting the reviewed contributions. Among the recalled issues, the different interpretations of TRIZ tools and the fundamental differences between TRIZ and FDM emerged as the most critical ones. Indeed, FDM has been conceived to support conceptual design activities, providing instructions and tools for transforming a set of requirements into potentially suitable concept variants of the product or system. Differently, the TRIZ base of knowledge has been developed to support the analysis of almost any kind of problem and the generation of potentially suitable solutions, not only within the context of conceptual design. Accordingly, some TRIZ tools can be usefully exploited also for task clarification purposes (Frillici et al., 2016). Moreover, although TRIZ is substantially based on the concept of contradictions, the concept of function plays an important role, representing the underpinnings for some inventive tools. This is a non-negligible problem when trying to combine TRIZ with FDM, because the related notions of function are disconnected, and sometimes also contradictory (Rousselot et al., 2012). The main differences between the EMS and the SAO functional models are resumed in Table 1.

Table 1. Main differences between the EMS and the SAO

	EMS	SAO
What a function is	Functions are actions performed by the system, which modify specific flows of energy, material and/or signal.	Functions are actions performed by a generic subject, which modify the properties of a generic receiving object.
What the model is for	1. Designing new concepts, allowing to construct the related function structure. 2. Decomposing existing technical systems in terms of functions and EMS flows, allowing finding alternative function structures or working principles.	1. Performing analysis on existing systems, to understand how they work and to find functional relationships among their physical components. 2. Finding insufficient, excessive or harmful actions for supporting the identification and the formulation of contradictions to be solved.

Another important difference between TRIZ and FDM, is that while the latter is grounded on a shared vision about how it should be used and implemented, the application of TRIZ tools can be affected by different and subjective interpretations. Recently, the recalled problem has been faced by the German VDI 4521 (Hiltmann et al., 2015), which proposes a standard guideline for the selection and use of TRIZ tools. However, the actual diffusion and acceptance of the recalled normative among TRIZ practitioners is still unclear.

Nevertheless, it is possible to assert that the SAO model can be used to highlight functional criticalities between two physical components (i.e. the subject and the object), then supporting the formulation of the problem to be solved. This observation, together with the differences summarized in Table 1, allows to highlight the difficulties behind any attempt to integrate TRIZ within FDM or vice versa. More precisely, the information available in the EMS function structure is not sufficient to build the SAO function model of a system. Indeed, while "Actions" can be directly extracted from EMS function boxes (see Figure 2) and "Objects" (i.e. the recipients of the functions) could be identified among one or more processed flows, no information is present about the "Subjects" that perform each function.

Therefore, the EMS function structure of a system highlights the relationships between functions and involved EMS flows but cannot highlight the presence of PP and/or HE problems, since solutions implementing each function (i.e. the Subjects of the SAO triads) are not represented. In fact, in the FDM approach, the solutions variants implementing the system functions (i.e. the working principles (WP) in FDM) are listed in the morphological chart only when the EMS function structure has been conceived.

More in general, to identify PP and HE problems it is necessary "at least" to know the working principle implementing each function. Furthermore, HE problems about undesired effects exchanged between two or more components of the system may arise only during the combination of the different WPs. Eventually, some scholars also specify that both Subject and Object of the SAO model have to be physical (or material) elements (Fey and Rivin, 2005), thus neglecting energy and signal flows of the EMS model.

According to the current available proposals for integrating TRIZ into FDM (Fiorineschi et al., 2018), two possibilities exists: trying to indirectly support FDM by applying TRIZ tools separately (support strategy), or trying to modify one of the two approaches (or both) to allow a concurrent exploitation of the related potentialities (merging strategy). Both the strategies present non-negligible flaws, since while the support one could lead to a more complex and onerous design process, the merging strategy fails in preserving the fundamentals of the two approaches, and then it is unclear whether the originally claimed advantages are preserved or not. In light of the recalled issues and differences, it is possible to assert that any attempt devoted to force TRIZ into the FDM process is destined to fail or, at least, to face many practical and theoretical issues that are currently not solved.

Therefore, trying to summarize the above mentioned criticalities that hinder a systematic exploitation of TRIZ in FDM-based SCD processes, the following issue is considered here as representative of the problem: "impossibility to identify PP and HE problems in FDM until (at least) the specific working principle has been selected for a specific function".

3. Overcoming the observed criticalities for exploiting TRIZ in SCD

A possible solution for exploiting TRIZ to enhance creativity in SCD processes, could be that of considering an alternative paradigm that preserves the systematic features of FDM and adopts logic and formalisms suitable to TRIZ.

Since TRIZ is a problem solving approach, it would be preferable to work directly on problems explicitly represented in a form capable to allow the identification of each term of the SAO triad, and to understand the nature of the actions (i.e. SM, PP, HE). Currently, such a type of SCD approach is not available in literature, but an alternative to FDM has been recently proposed by Fiorineschi et al. (2016), i.e. the Problem-Solution Network (PSN), where instead of reasoning in terms of functions, the conceptual design process is intended as a co-evolution of problems and related solutions. Even if the SAO model is not explicitly addressed by the recalled method, the following paragraphs show that PSN implicitly contains information to represent a problem according to the SAO triad.

The PSN is based on the construction of a network of problems and solutions (see Figure 3) by following a set of six fundamental rules (see Table 2) and an Analysis-Synthesis-Evaluation logic for passing from each problem to each related solution (Fiorineschi et al., 2016).

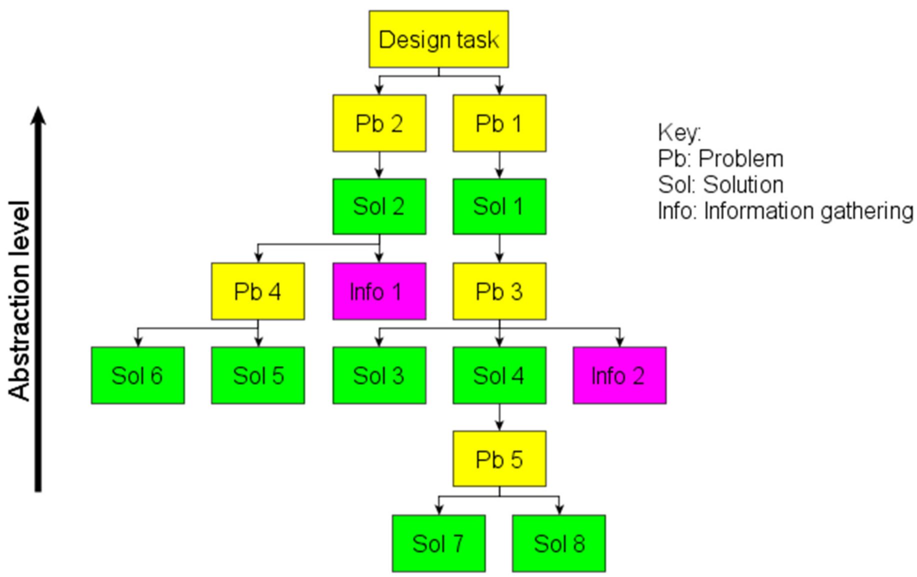

Figure 3. A generic PSN network

In particular, the PSN approach provides specific indications about how to formulate problems, i.e. in form of "How to verb + noun?". More specifically, the recalled formulation could express the functions that the designed system should deliver (e.g. "How to import human hand?", where "import human hand" is the function according to the EMS formalism), but could express also any other desired features that it should have (e.g. "How to ensure system adaptability?").

As already said, the terms of the SAO triad are not explicitly represented in the PSN, as well as the information about the nature of the actions. Nevertheless, an analysis of problem and solution boxes contained in the PSN could reveal the needed information. Let consider for instance the generic PSN branches represented in Figure 4.

Table 2. Short introduction to the six PSN rules (Fiorineschi et al., 2016)

PSN rule	Description
Main task formulation	The very first problem box of the net represents the overall design task.
First-level problem formulation	The first level of solution-independent problems concern how to implement the main functions that the system has to carry out.
Solution-independent problem decomposition	A direct "problem-problem" decomposition Step is allowed only if the decomposition is actually not influenced by an implicit solution.
Correct sequence of abstraction levels	The highest possible level of abstraction has to be reached, both in the identification of solutions and in formulation of problems.
Independency of the PSN branches	Each branch is independent on the others during his growth.
Completeness of the PSN	At least one complete problem-solution path (i.e. ending with a solution) must be reached for all of the "first-level" problems.

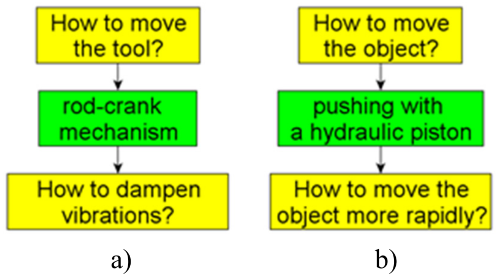

Figure 4. Generic PSN branches with information about the subject, the object, the action and the related nature

The problem in the last box of the "a" branch refers to dampening some "un-wanted" vibrations generated by a "rod-crank mechanism", which is the solution identified for the upstream problem "how to move the tool?". In this case, there is something in the system, i.e. the "rod-crank mechanism" that performs two actions: on the one hand, it "moves" the tool but, on the other hand, it puts in vibrations the systems itself. Therefore, the analysis of the information available in the considered branch of PSN leads to extract the following SAO triads:

1. S (Rod-crank mechanism) - A (Moves) - O (Tool)
2. S (Rod-crank mechanism) - A (Puts in vibration) - O (The rest of the system)

Since the nature of the action "puts in vibration" is harmful (otherwise the need of formulating the problem "how to dampen vibrations?" did not emerge in the PSN), the problem represented by the second SAO triad can be easily assigned to the "HE" category.

Furthermore, the reader could observe that by considering the problem "how to dampen vibrations?", it is also possible to extract the following SAO components:

- S (missing) - A (Dampen - not yet provided) - O (Vibrations)

The above SAO triad is clearly incomplete, since the subject is missing. Therefore, it represents a problem referred to the identification of an element that provides the required action (Dampen), which belongs to the SM category. Unfortunately, some TRIZ scholars specify that both, subject and object, have to be physical (or material) elements (Fey and Rivin, 2005), then excluding "vibrations" from the possible objects. Accordingly, such a type of PSN-to-TRIZ conversion is incorrect.

The problem "How to move the object more rapidly", shown in the "b" branch of Figure 4, refers to a function performed by a hydraulic piston (i.e. the parent solution), which has been used for solving the upstream problem "how to move the object?", whose performance in moving an object is not sufficient. Therefore, the SAO triad is the following one:

- S (Hydraulic piston) - A (Moves - not enough rapidly) - O (Object)

Consequently, since the action is insufficiently performed, it is possible to assert that the problem expressed by the SAO triad belongs to the PP category.
Concerning the upstream problems of each branch represented in Figure 4 (i.e. "How to move the tool?" and "How to move the object?"), it is possible to formulate the SAO triad with a "missing" subject for exploiting TRIZ to find alternative solutions, potentially neglecting the lower-level problems. For instance, in the "a" branch of Figure 4, for the PSN problem "How to move the tool?" the following SAO can be formulated:

- S (missing) - A (Moves - not yet provided) - O (Tool)

In this way, specific TRIZ tools like the "Effect Database" (AULIVE, n.d.; Triz.co.uk, n.d.) or the Ideal Functional Result (Gadd, 2011) could be used to support the designers in finding suitable subject variants for performing the required action, and then to expand the PSN with more alternative branches.
Therefore, according to the above considerations, the PSN contains the information needed to extract all the three categories of problems (SM, HE and PP)
It is worth to notice that in this way, the designer is potentially able to systematically find chances to apply TRIZ during the SCD process, but the selection of the most suitable tool and its application cannot overlook the expertise level currently required for applying TRIZ.

4. Application examples

In this section, three academic examples are reported to show how TRIZ could be exploited in problem solving activities related to SCD processes, by following the PSN-SCD approach and the considerations performed in Section 3. More specifically, an example is reported for each of the three problem categories (SM, PP, HE), where the specific problem to be faced with TRIZ is identified according to the related SAO triad, and a suitable tool is applied to find a solution.

4.1. Subject-missing problems

The example refers to the re-design of a domestic clothes airer, where the specific task requires to find alternative solutions to the clothespin, i.e. the current clothes fastening device. Once the current system has been modelled according to the PSN rules (Figure 5), the following problem appears in a specific branch of the network: "How to fasten the clothes on a wire?", which is the parent functional problem solved by the clothespin. In this case, searching for new solutions necessarily implies to neglect the current solution, then leaving the "fasten" function unimplemented. Consequently, the related SAO triad can be modelled as shown in Figure 6.

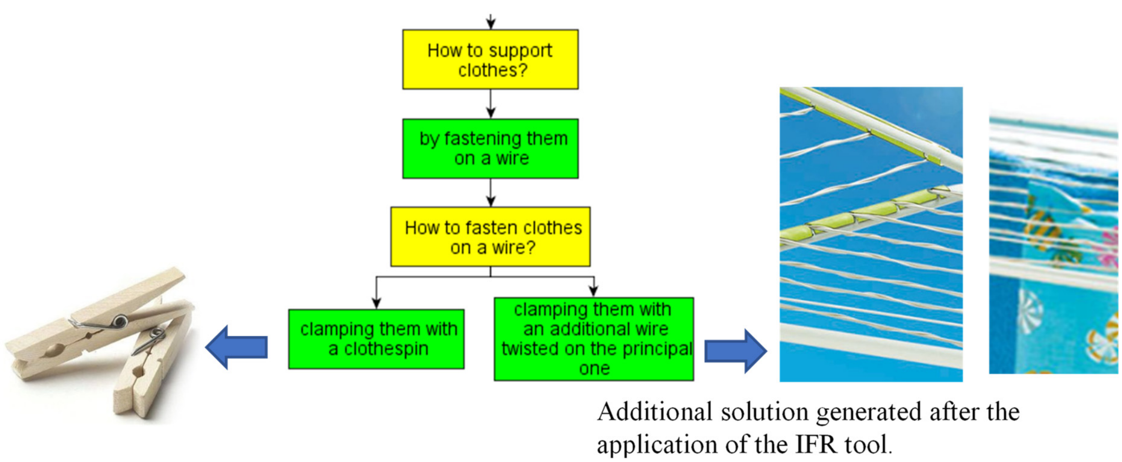

Figure 5. PSN branch of the modelled airer system, with the additional solution generated after the application of the IFR tool

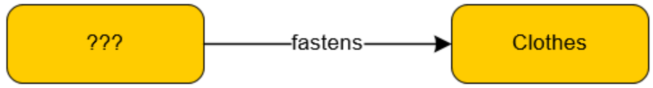

Figure 6. SAO triad with missing subject

Among the available TRIZ tools, the Ideal Final Result (IFR) (Gadd, 2011) can be used. Accordingly, the IFR can be expressed as: "A resource of the system fastens the clothes by itself, without any harmful effect". Considering that the initial PSN has been drafted around the current solution (Figure 5), particular IFRs can be formulated like "The wire (or thin rod) fastens the clothes by itself without any drawbacks" or "The clothes fasten by themselves". In this way, it is possible to overcome design fixation on clothespins, and to facilitate the generation of sensibly different but elementary solutions, as the additional one shown in Figure 5 (i.e. clothes are fastened between two twisted wires).
The insertion of the new solution in the PSN allows consider the related (if any) sub-problems and to face them by a systematic approach. Moreover, if solution generated for the considered problem are not sufficiently satisfactory, higher level problems (e.g. "How to support clothes?" in Figure 5) could be faced in order to find even more different solutions (e.g. not considering the presence of a wire).

4.2. Performance problems

This particular example refers to a simplified PSN schematization of a domestic dishwashing machine, where a jet of hot water mixed to soap is currently used to remove filth from dishes (Figure 7). More specifically, since it has been observed that the filth is not completely removed when in presence of hard encrustations on dishes, an additional problem can be formulated as "How to enhance filth removal?" (Figure 7).

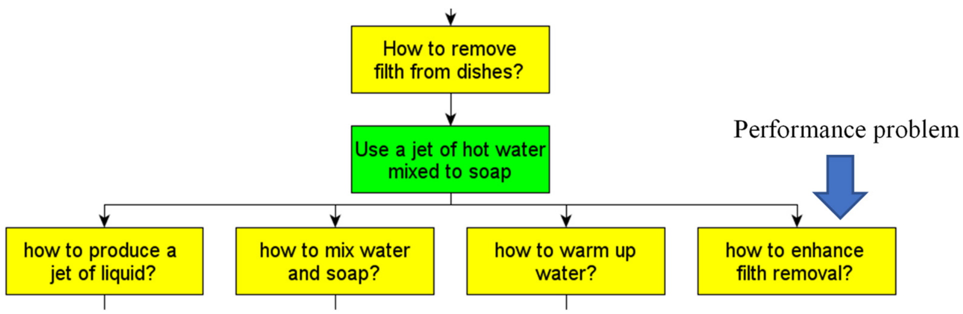

Figure 7. Part of the PSN branch related to the main required function of a common dishwashing machine

In this case, thanks to the presence of the word "enhance" it is quite clear that the parent solution (i.e. the jet of hot water mixed to soap) does not sufficiently implement the required main function (i.e. removing filth from dishes), and the problem can easily identified as a "performance problem". Accordingly, the SAO triad can be represented as shown in Figure 8.

Figure 8. SAO triad representing the insufficiently performed function "Remove"

Among the available TRIZ tools, Su-Fields model and Standard Solutions (Salamatov, 1999) can be used for supporting problem resolution. Accordingly, the SAO triad leads to the Su-Field model represented in Figure 9a. Then, among the available Standard Solution, the 1.1.2 (Salamatov, 1999) could provide some useful hints. Indeed, Standard Solution 1.1.2 suggests to "add an external substance in the S1 or S2, in order to sufficiently perform the action" (Figure 9b).
Assuming for example to introduce an additional substance in the jet of hot water and soap mix, it would be possible to imagine some hard particles mixed in the main liquid flow, impacting on encrustations and then facilitating their removal. In other words, it means to add a sort of sandblaster working principle. The particles could be added as an additional flow of material in the overall dishwashing system, or internal resources could be exploited, e.g. by using salt crystals commonly used for softening

the water. In any case, by inserting the solution "add solid particles to the liquid flow" in the PSN, it is possible to systematically face the related sub problems (e.g. "How to import solid particles in the liquid flow?") and to go ahead with the systematic design process.

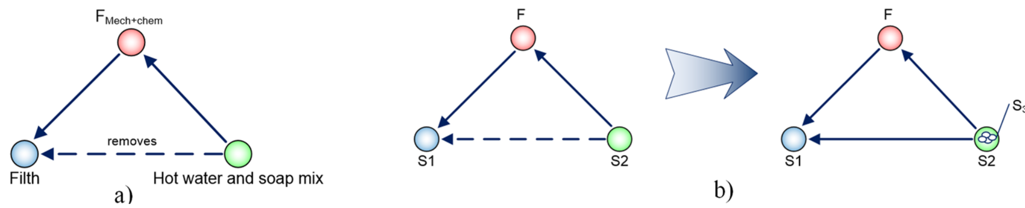

Figure 9. a) Su-Field model of the SAO triad represented in Figure 8 - b) Model of the Standard Solution 1.1.2

4.3. Harmful effect problems

The example refers to the design of an anodizing system for aluminium bars, where a specific branch of the PSN concerns a specific function, i.e. the removal of impurities before the anodization process. As shown in Figure 10, aluminium bars are submerged in a hot acid solution (at approximately 90°C), contained in a big opened tub.

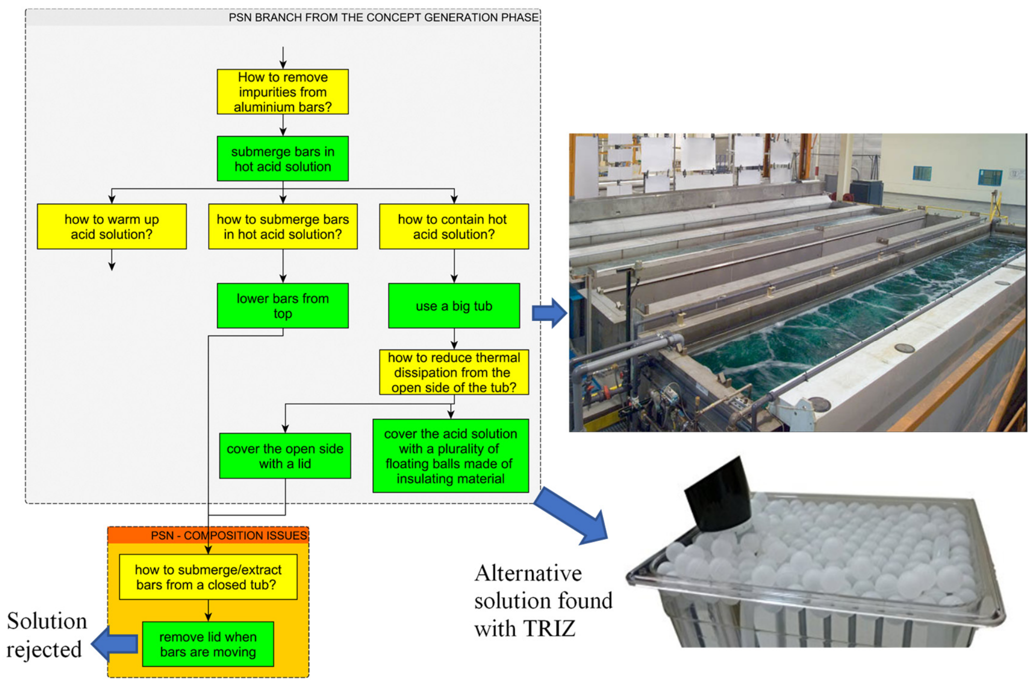

Figure 10. PSN branch for the example, and a picture of the tub

However, due to the extension of the open surface of the tub (1m x 4m), a non-negligible thermal dissipation is present, and consequently it is necessary to spend a lot of energy to maintain the acid at the desired temperature. In this case, the simple application of a lid on the open side of the tub is a quite trivial solution (see the PSN in Figure 10). Unfortunately, when composing the solutions from different branches (Fiorineschi et al., 2016), the presence of a lid necessarily implies to hinder the submersion-extraction of the bars from the acid (see composition issues in Figure 10). The obvious solution to this incompatibility problem is to remove the lid when the bars are moving (Figure 10), but this solution is not acceptable due to the technical complications and the non-negligible thermal dissipation when the lid is removed for bar submersion. In order to find alternative and non-obvious solutions to the removable lid, the application of TRIZ inventive tools can be exploited. Accordingly, it is necessary to identify a suitable Action-Object couple, and then a physical subject, representing the actual problem to be solved. In this case, by analysing the PSN branches shown in Figure 10, it is possible to identify a specific SAO triad, where the lid (i.e. the current solution to reduce thermal dissipation) constitutes the subject, which negatively acts by hindering (i.e. the action) the movements required for bars (i.e. the object). Accordingly, the action is evidently "harmful" (Figure 11), and the problem to be solved with TRIZ belongs to the HE category.

Figure 11. SAO triad extracted from the PSN branch of Figure 6. The harmful action has been represented with a specific red wavy arrow

It is now necessary to select a specific TRIZ tool, and for example, if selecting the application of Separation principles (Gadd, 2011), it is necessary to model the contradiction behind the problem. Accordingly, the identified contradiction relates to the lid: we need a big lid (covering all the tub) to reduce thermal dissipation, but we also need a very small lid to ease the submersion of the bars into the acid solution. To solve the identified contradiction, it is possible to apply one or more of the Separation principles, i.e. the Separation in space, the Separation in time, the Separation on condition and the Separation between the macro and micro level (Gadd, 2011). The application of the latter principle implies to answer "No" to the following question: "Do we really want a big lid in the system as a whole and in all of its parts/subsystems, and we also really want a small lid in the system as a whole and in all of the its parts/subsystems?". In other words, is it possible to imagine a big lid as a whole but made by a plurality of small lids? Alternatively, is it possible to imagine a small lid as a whole but made by big lids? The latter question has no sense, while the previous one allows thinking about a cover for the tub, which is composed by many little parts that can be moved directly by the bar during its immersion. For example, this idea can be realized by covering the acid solution with multiple layers of floating balls made by insulating material, which can be easily moved by bars themselves when inserted into the tub (see Figure 10).
To correctly insert this solution in the PSN, it is necessary to identify that it does not directly solves the problem related to "How to submerge bars", but it is an alternative solution for "reducing thermal dissipation" that avoid the incompatibility issue risen by the presence of a monolithic lid. Accordingly, the related solution box (green) should be inserted under the problem "How to reduce thermal dissipation from the open side of the tub?" (see Figure 10).

5. Discussions, research hints

Besides the advantages originally claimed for the PSN approach, the examples reported in this paper show that its problem-solution co-evolutionary logic and the related formalisms allow to overcome the incompatibilities observed between FDM and TRIZ. The observed affinity between PSN and TRIZ potentially leads to research hints concerning the development of methodological guidelines for a comprehensive integration. For instance, it has been shown in this paper that the information summarized in the PSN branches allows to identify SAO triads, then allowing to identify three problem categories to be faced with TRIZ tools. Therefore, the formulation of the problem in the PSN affects the identification of the suitable TRIZ tool to be applied for the solution process. Indeed, it is evident that a problem formulated like "How to remove encrustations?" is very different from "How to enhance filth removal?". since the first problem refers to SM while the second one belongs to PP. Therefore, different formulations lead to different problems categories, which in turn lead to the selection of potentially different TRIZ tools. The investigation about the effect (in terms of selected TRIZ tools and related problem solving support) provided by different formulations of the same PSN problem is thus a mandatory research activity. Indeed, while the identification of the SAO triad from PSN branches can be considered a sort of PSN-to-TRIZ translation of problems, a comprehensive guideline is still missing, to support designers in re-inserting new solution in the PSN (i.e. a sort of TRIZ-to-PSN translation of the generated solution). Indeed, in the TRIZ domain, the designer can find any kind of potential solution at different abstraction levels (e.g. a physical principle or even a precise structure) and with different formulations. However, the solutions generated with TRIZ should correctly inserted in the PSN to keep

track of the design space exploration, to manage and to go ahead with the design process. Therefore, future works should comprehensively consider this point, by providing detailed instructions for translating the solutions generated with TRIZ into a formulation compliant with the rules of PSN.
Another important limit of the proposal presented here concerns the subjectivity in the selection of the TRIZ tools to be used to solve problems. The selections of the tools used in the examples presented in Section 4 are based only on our experiences and expertise, but the latter cannot be considered as univocally shared. The selection of the most suitable TRIZ tool is another interesting research issue that arises from this investigation, regardless the specific application to SCD processes. Indeed, the availability of a selection framework, capable to put in relation the category of problem to be solved with the most suitable TRIZ tool, could provide non-negligible benefits to TRIZ practitioners. Case study applications, interviews and surveys could be useful research tools for this activity, whose outcome could potentially provide new insights for a comprehensive standardization in selecting and using TRIZ tools.

6. Conclusions

This paper, highlighted the main criticalities affecting TRIZ-FDM integration proposals, by extracting particular and specific limitations related to the identification of PP and HE problems in FDM. Consequently, the paper shows an alternative way for exploiting the benefits acknowledged for both TRIZ and SCD processes. More specifically, we suggested the PSN as the reference SCD approach, since it is claimed to overcome some FDM flaws and is grounded on a problem-solution co-evolutionary logic that can be considered a more fertile ground for integrating SCD with TRIZ. Three examples have been reported in the paper, i.e. one for each of the three identified problem categories, in order to show how TRIZ can be used within the PSN-SCD process in practice. Then, discussions have been provided about the current limits of the presented proposals, which led to a set of research hints about issues still affecting the TRIZ-SCD integration, with particular attention to the proposed TRIZ-PSN one.

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