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Integrated Use of TRIZ Tools in Systematic Conceptual Design

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Abstract.

Among the design methods available in literature, the German approach based on Functional Decomposition and Morphology (FDM) is one of the most taught in academia. However, notwithstanding the academic success, some scholars argued that such a method lacks a comprehensive support to the generation of innovative solutions. Due to its inventive potentialities, TRIZ has been often addressed as a potential aid to improve FDM even though the two approaches are characterized by non-negligible differences. An alternative to FDM has been recently proposed, which overcomes some FDM flaws and integrates the potentialities of TRIZ. It is based on the formulation of the design tasks in terms of problems and solutions. The new approach is called “Problem-Solution-Network” (PSN), where the main graphical tool is a hierarchical network of problems and solutions, whose construction follows a set of specific rules. The objective of this paper is to show the potentialities of the PSN-TRIZ integration.

The paper presents a literature review of the background related to the integration of FDM and TRIZ, the main features and constructs of PSN and its integration with TRIZ tools to show how the approach works.

Keywords: TRIZ, Conceptual design, Engineering design, Problem solving, Design

1 Introduction

In the last decades, the design process has been deeply investigated, leading to a variety of contributions about models and methods. The motivations behind these research efforts can be found in the critical nature of the engineering design activities, since directly affecting all the subsequent life cycle phases. In particular, for the early phases of the design process, taken decisions are acknowledged to influence about 80% of product costs [1]. In this context, the well-known approach based on Functional Decomposition and Morphology (FDM) [2] is one of the most taught in academia and refers to a specific concept of "function" and function structures. Notwithstanding the

achieved academic success, non-negligible flaws have been highlighted for FDM, leading some scholars to argue about its actual potentialities and/or to propose potential alternatives [3, 4]. Maybe the most critical among the identified flaws of FDM, is the lack of a comprehensive support to the generation of innovative solutions [5]. To overcome these issues, some scholars suggested to exploit the potentialities of TRIZ tools [6]. However, the task of integrating TRIZ into FDM is not trivial, because the two approaches are characterized by non-negligible differences. 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 still plays a crucial role, but is based on completely different concepts. Additionally, TRIZ is strongly based on the concept of "contradiction", not present in FDM.

However, a recent alternative to FDM has been proposed, which is based on more intuitive concepts of problems and solutions, and which has been successfully integrated with TRIZ tools [7]. The new approach is called "Problem-Solution-Network" (PSN), where the main graphical tool is a hierarchical network of problems and solutions, whose construction follows a set of specific rules [8, 9].

The objective of this paper is to show the potentialities of the PSN-TRIZ integrations, by means of some application examples. Accordingly, the paper contents have been distributed as follows.

In section 2, a short introduction is reported about the acknowledged attempts to integrate FDM with TRIZ. Section 3 introduces the PSN approach, describing how it has been upgraded through TRIZ tools. Section 4 shows the PSN-TRIZ application examples, and a comprehensive discussion is reported in Section 5, together with conclusions.

2 Background: TRIZ-FDM integration issues

Several methods have been suggested for supporting the generation of creative solutions in the German systematic design by the same Pahl and Beitz [2], but not directly referring to TRIZ. However, the latter has been considered in other valuable design textbooks [1, 10]. Focusing the attention on TRIZ, ten TRIZ/FDM integration proposals currently available in literature have been recently discussed [6], 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, TRIZ is substantially based on the concept of contradictions, while the FDM approach is based on the concept of function. However, the concept of function plays an important role also in TRIZ, because it constitutes 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 very different, and sometimes also contradictory [11].

More in particular, FDM is strongly based on the concept of "functions", i.e. actions performed by the system, and capable to transform one or more Energy-Material-Signal (EMS) input flows into modified outputs (Figure 1).

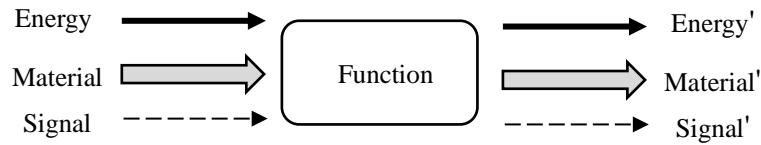


Fig. 1. EMS functional model [2].

Differently, the TRIZ definition states that functions are actions between two components, i.e. the subject (the component providing the action), and the object (the component that receives the action) [12, 13]. Accordingly, the TRIZ function is delivered by a set of three elements: subject (S), action (A) and object (O) (Figure 2), which is often called SAO triad [13].

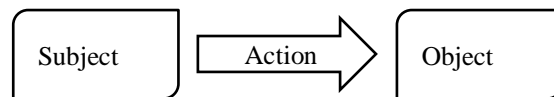


Fig. 2. SAO triad.

More specifically, the action "A" modifies or preserves one or more parameters of the object "O" [13, 14], and can be classified in TRIZ as useful actions, insufficient actions (or even excessive), and harmful actions:

- Useful actions/functions lead to a positive (required) change or preservation of a value of a parameter of the object of the function;
- Insufficient (or excessive) actions/functions lead to a positive change or preservation of a value of a parameter of the object of the function, but with fewer degree of performance than required (or the action is performed with the use of a non-optimal amount of resources);
- Harmful actions/functions lead to unacceptable change or unacceptable preservation of a value of a parameter or a state of another material object.

By referring to these three actions categories, it is possible to classify problem solving activities into three families:

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

In a few words, it is possible to assert that 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 1) and "Objects" (i.e. the recipients of the functions) could be identified among one or more

processed flows, it is not possible to identify the "Subjects" that perform each function. According to the current available proposals for integrating TRIZ into FDM [6], two possibilities exist: 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). However, both strategies present critical flaws. Indeed, while the support strategy could lead to a more complex and onerous design process, the merging strategy fails in preserving the fundamentals of the two approaches. 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 still unsolved.

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 can be characterized by different and subjective interpretations. Accordingly, this problem has been faced by the German VDI 4521 [15], which proposes a standard guideline for the selection and use of TRIZ tools. Unfortunately, the actual acceptance rate of such a normative among TRIZ practitioners is unclear.

3 The Problem-Solution Network and TRIZ

A possible solution for exploiting TRIZ to enhance creativity in systematic conceptual design is to consider an alternative paradigm that preserves the systematic features of FDM and adopts logic and formalisms suitable to TRIZ. For that purpose, the recently proposed PSN approach has been used [7], where instead of reasoning in terms of functions, the conceptual design process is intended as a co-evolution of problems and related solutions. In the following subsections, the fundamentals of the PSN approach are presented, together with the related integrations rules for a correct integration with TRIZ.

3.1 Fundamentals of the PSN approach

The PSN main tool is a network of problems and solutions mutually connected by a co-evolutionary relationship, where a generic solution to a generic problem is a potential source of specific sub-problems related to the solution itself (Figure 3). However, it is important to not confuse the PSN network with the Network of Problems (NoP) of OTSM-TRIZ [16]. Indeed, the PSN approach does not have any relationship with TRIZ (or any of its developments). More precisely, the PSN follows a set of rules that are not contemplated in the NoP. Additionally, the information gathering process required in each step of the problem-solution co-evolution process is also mapped in the PSN, and can strongly influence the design space exploration [9].

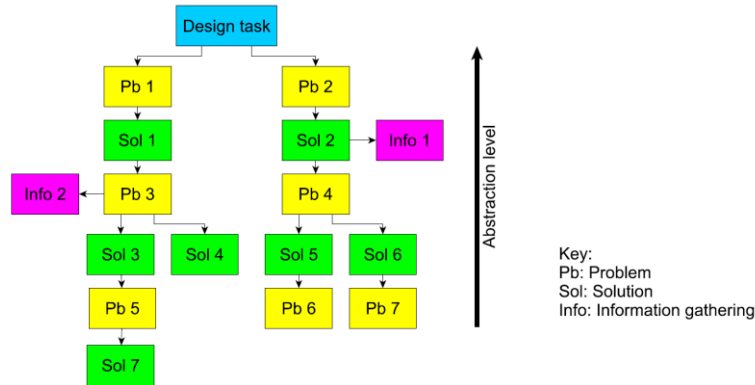


Fig. 3. The PSN main tool, according to [8].

The PSN problems are formulated in the form of "How to verb + noun?", expressing the actions that the designed system should deliver (e.g. "How to move the bar?", where "move the bar" is the function according to the EMS formalism). Additionally, the PSN problems can relate to the need of implementing a function by means of specific behaviours (e.g. "How to exploit gravity to move the piece?"). Moreover, the PSN network must be composed by following the set of six rules reported in Table 1.

Table 1. PSN rules [9].

PSN rule	Description
Main task formulation	The very first problem box abstractly represents the design task.
First-level problem formulation	The first row of PSN problems concerns how to implement the main functions that the system has to carry out.
Solution-independent problem decomposition	"problem-problem" decomposition is allowed only if the decomposition is actually not influenced by an implicit solution between the two problems.
Correct sequence of abstraction levels	The highest possible level of abstraction has to be reached, both in the identification of solutions and in the formulation of problems.
Independency of the PSN branches	Each branch must be developed independently, ignoring the development of other branches.
Completeness of the PSN	At least one complete problem-solution path (i.e. ending with a solution) must be reached for each "first-level" problem.

The first rule leads to the definition of the overall task, allowing the PSN to reach the highest level of abstraction according to the available set of design requirements.

The second rule in Table 1 indicates to decompose the main design task into solution-independent problems. In particular, a "solution-independent problem" is intended as a problem formulated without any preconceptions regarding the final solution. The

third rule suggests to reflect about the reasons that could lead to sub-problems extracted from a main problem. In particular, in engineering design problems it is improbable to find a direct problem-problem decomposition (according to the PSN formulation) because the formulation of sub-problems depends on the considered solution. In other words, from the same main problem, different sub-problems can be identified, depending on the considered solution variant (see Pb6 and Pb7 in Figure 3).

The rule about the correct abstraction level has been formulated in [9] by referring to two questions that the designer should ask herself/himself:

- “Does the formulated problem implicitly consider the adoption of a specific solution at a lower level?”
- “Does the proposed solution belong to a more extended (or more abstract) family of solutions?”

Additional and more detailed instructions are provided in [8], where a simplified version of the Function-Behavior-Structure [17] is used to discern the different abstraction levels (not used in this paper).

The rule about the independency of the PSN branches forces the designer to not consider interaction problems (i.e. problems related to the combination of solutions belonging to different branches) during the concept generation phase, and develop the PSN branches independently. Anyway, it does not imply a loss of information, because all the different ideas are stored in different branches of the net, and interaction problems are considered in a subsequent phase, i.e. the “concept composition” one [8].

Eventually, the last rule ensures that each problem that is defined through the “first level formulation” rule, has been sufficiently investigated during the concept generation process. Accordingly, the rule also implies to complete the information gathering activities (represented by the pink boxes in Figure 3). If the information required about a proposed solution is not found (within the time limits of the project schedule), this solution should not be considered. However, the solution is stored in the net, and can be deeply investigated in future developments of the project.

3.2 The TRIZ-PSN integration

Although the terms required to formulate the SAO triad are not explicitly represented in the PSN, an analysis of the related problem and solution boxes can reveal the needed information [7]. For example, it is possible to consider the generic PSN sequence represented in Figure 4.

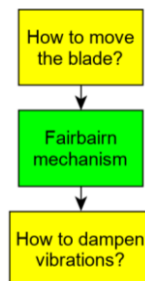


Fig. 4. Generic example of PSN's problem-solution sequence.

The problem in the last box of the branch refers to dampening some "un-wanted" vibrations generated by a "Fairbairn mechanism", which is the solution identified for the upstream problem "how to move the blade?". In this case, there is something in the system, i.e. the "Fairbairn mechanism" that performs two actions: it "moves" the blade but, it also 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 (Fairbairn mechanism) - A (Moves) - O (Blade)
- 2. S (Fairbairn mechanism) - A (Puts in vibration) - O (The rest of the system)

The nature of the action "puts in vibration" is harmful. Therefore, the problem represented by the second SAO triad can be easily assigned to the "HE" category.

In a similar way, also problems for the three categories listed in Section 2 (SM, HE, PP) can be extracted from the PSN, and a set of preferred TRIZ tools have been suggested to support the designer [7] (see Table 2). However, it is worth to notice that the considered selection is based only on authors' personal experience. Therefore, we cannot exclude that each tool can be potentially suitable for all problems.

Table 2. TRIZ tools suggested for each problem category.

	SM	PP	HE
Ideal Final Result	X		X
Resources Analysis	X	X	X
Effect Databases	X		
Smart Little People	X	X	X
Size-Time-Cost operator	X	X	X
Standard Solutions	X	X	X
Separation and Inventive Principles			X

Concerning SM problems, all the tools that can help the designer in implementing a needed function are potentially suitable for this category of problems. Differently, TRIZ tools developed to model and solve contradictions cannot be used for this category. Indeed, no solution has been identified yet, then no subject exists that can provide any type of function (neither useful nor harmful).

Similarly, also for the PP category, the contradictions toolkit cannot be used. Indeed, only a useful function is delivered, although insufficient or excessive, so that no contradiction is explicitly present. Moreover, IFR is not in case of performance problems, because for performance problems the system already exists. Additionally, ED cannot be exploited for overcoming flaws related to a predetermined way to implement a function. For the same reasons, ED has not been considered suitable for HE problems. Differently, TRIZ tools developed to model and solve contradictions are useful for HE problems, since contradictions may arise due to the presence of undesired conditions.

4 PSN-TRIZ application examples

4.1 Subject-missing problems

A domestic airer has been modelled according to the PSN rules (Figure 5). The problem "How to fasten the clothes on a wire?" has been identified and formulated, i.e. the problem solved by the clothespin. Supposing the need to search for alternatives to the clothespin, the designer should imagine the "fasten" function as still unimplemented. Consequently, the related SAO triad can be modelled as shown in Figure 6.

According to Table 2, the Ideal Final Result (IFR) [13] can be used, and expressed as: "A resource of the system fastens the clothes by itself, without any harmful effect". 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 psychological inertia on clothespins, thus allowing the generation of sensibly different solutions. Accordingly, an additional solution has been added to the PSN branch (i.e. clothes are fastened between two twisted wires).

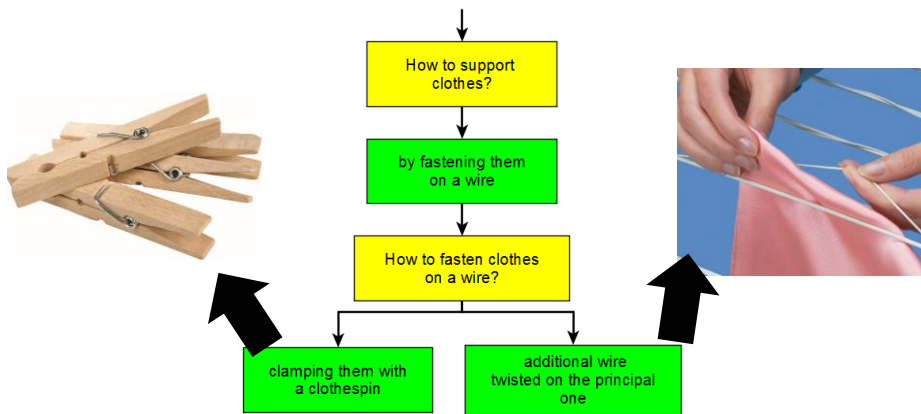


Fig. 5. PSN branch showing the clothespin solution and the alternative one found with the support of the IFR tool.



Fig. 6. SAO triad used to find the alternative to the clothespin.

4.2 Performance problems

This example refers to 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).

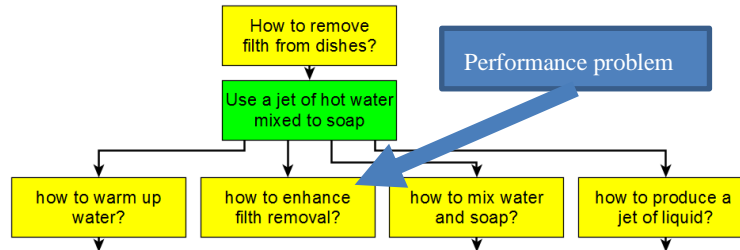


Fig. 7. PSN branch used to mode the dishwashing performance problem.

The presence of the word "enhance" reveals that the parent solution (i.e. the jet of hot water mixed to soap) does not sufficiently implement the main function. Accordingly, the problem can be considered as a PP one. Consequently, the SAO triad shown in Figure 8 can be drafted.



Fig. 8. SAO triad for the insufficient performance of the action "remove".

According to Table 2, Su-Fields model and Standard Solutions can be used in this case, leading to the Su-Field model of Figure 9a. Then, the Standard Solution 1.1.2 [18] suggests to "add an external substance in the S1 or S2, 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, working as a sort of sandblaster. Therefore, by adding the solution "add solid particles to the liquid flow" in the PSN branch, 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 design process.

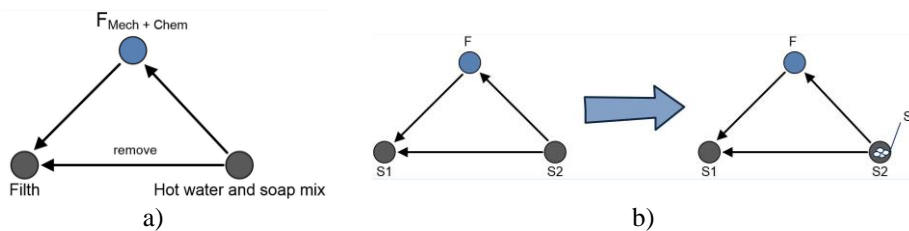


Fig. 9. a) Su-Field model of the SAO triad of Figure 8 - b) Model of the Standard Solution 1.1.2.

4.3 Harmful effect problems

As shown in Figure 10, aluminium bars are submerged in a hot acid solution (at approximately 90°C), contained in a big opened tub. However, due to the extension of

the open surface of the tub, it is necessary to spend a lot of energy to maintain the desired working temperature. The simple application of a lid on the open side of the tub is a quite trivial solution (see the PSN in Figure 10), which cannot be considered satisfactory since the presence of a lid necessarily implies to slow both the bar submersion and extraction processes (time spent to move the lid). In order to find alternative and non-obvious solutions, it is necessary to identify a SAO triad 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 the lid (i.e. the current solution to reduce thermal dissipation) as 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).

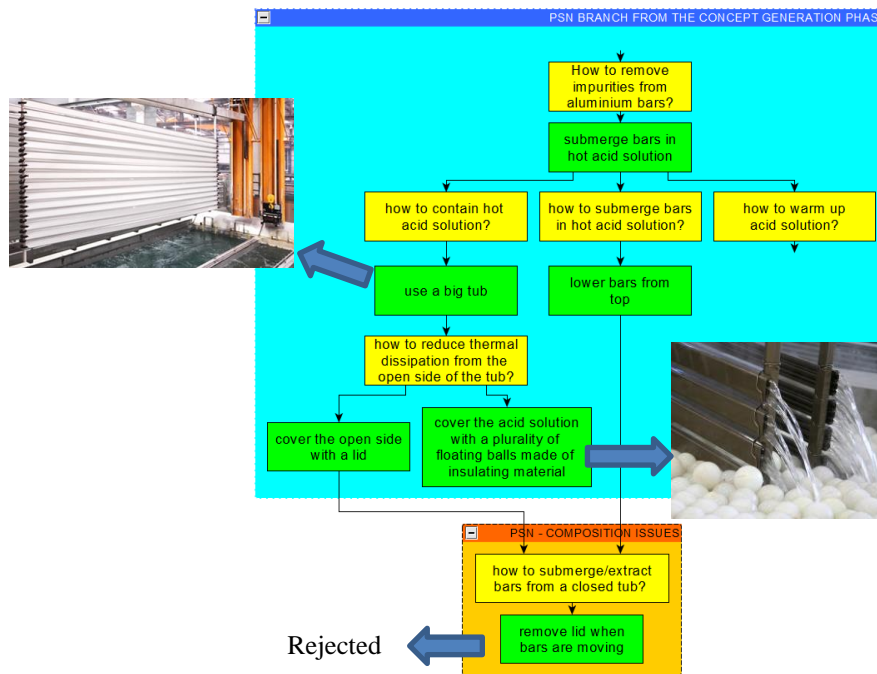


Fig. 10. PSN branch for the anodization tub example.



Fig. 11. SAO triad highlighting the harmful effect of the lid.

According to Table 2, Separation principles [13] can be considered, but it is necessary to model the contradiction behind the problem: 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 [13]. The application of the latter principle implies to imagine a big lid as a whole but made by a plurality of small lids, i.e. 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).

This additional solution can be added in the PSN, by considering it is an alternative solution for "reducing thermal dissipation" that avoid the incompatibility issue risen by the presence of a monolithic lid. Therefore, the solution should be inserted under the problem "How to reduce thermal dissipation from the open side of the tub?" (see Figure 10).

5 Discussions and conclusion

The examples presented in this paper highlight that the problem-solution co-evolutionary logic of the PSN allows to overcome the incompatibilities between FDM and TRIZ, thus allowing an efficient exploitation of the TRIZ knowledge for engineering design purposes. Nevertheless, the suggested integration should be improved by means of comprehensive guidelines. Indeed, the information summarized in the PSN branches allows to identify SAO triads and the three problem categories to be faced with TRIZ tools. This implies that the formulation of PSN problems influences the selection of the TRIZ tools, best suited for the solving process. More specifically, different formulations lead to different problems categories, which in turn lead to the selection of potentially different TRIZ tools. Additionally, a comprehensive guideline is still missing to support designers in re-inserting new solutions in the PSN. 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, to keep track of the design space exploration, the solutions generated with TRIZ need to be correctly inserted in the PSN. Accordingly, a further research hints consists in developing structured guidelines to support designers in re-inserting the solutions obtained with TRIZ into the PSN formalism.

Another criticality of the PSN-TRIZ integration concerns the subjectivity in the selection of the TRIZ tools, which is currently based only on the personal experiences and expertise of the user. Therefore, the selection of the most suitable TRIZ tool is another interesting research issue that, if comprehensively faced, could lead to an efficient tool selection framework. Case study applications, interviews and surveys could be useful research sources for this activity, whose outcomes could potentially provide new insights for a comprehensive standardization in selecting and using TRIZ tools.

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