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Applications of TRIZ and Axiomatic Design: a Comparison to Deduce Best Practices in Industry

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Abstract

In the first decade of 2000s, several contributions have illustrated methods combining TRIZ and Axiomatic Design (AD). The strength of the connection was found in the complementary objectives AD and TRIZ pursue. AD is supposed to analyze the problem and structure it in the most convenient way, while TRIZ should solve the minimum number of design conflicts that are intrinsically present in a case study.
Nevertheless, despite the promising match between AD and TRIZ, no conjoint application strategy has emerged as a reference, neither in academia, nor in industry. Conversely, the quantity has dropped of scientific papers contextually making reference to both methodologies.
Some studies attempt to remark the methodological problems concerning the combination of AD and TRIZ. In a different perspective, the authors performed an application-oriented study, in order to point out the industrial domains for which the methodologies result the most suitable. The survey highlights that TRIZ is mostly employed for mass-market products, while AD is basically used to develop systems that industrial organizations make use of. The authors discuss the consequences of these findings, inferring how design can benefit from TRIZ and AD heuristics and the practical cases in which they are likely to be combined successfully.

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Keywords: TRIZ; Axiomatic Design; best practices; industrial sectors

1. Introduction and background

One of the main concerns of TRIZ advocates regards the difficulties that emerge when employing this theory to face complex problems. Evolutions of TRIZ body of knowledge are expected in terms of enhancing its capability of supporting the mutual solution of multiple contradictions [1]. Actually, at the current stage of evolution, different approaches exist to tackle complex systems.

An opportunity stands in schematizing technical systems appropriately with the aim of identifying a manageable quantity of elements to be taken into account contemporarily [2], such as through the construction of a Mini-Model. This option deliberately simplifies the task, attempting to deal with few relevant contradictions at once. However, the poor repeatability of the built models warns against the troublesome process of identifying the most relevant problem for a specific technical system.

Another strategy is represented by the implementation of Root Cause Analysis in problem solving tasks carried out with TRIZ. Thanks to a cause-effect schema, it is supposed to point out a fundamental problem from which other system limitations originate. At the same time, it is claimed that the solution of such an individuated problem can release other contradictions. A recent illustrative application is documented in [3].

It is worth noting that the above-mentioned instruments, which can be used to undertake complex problems at the beginning of the conceptual design phase, do not range among the most well-known TRIZ-based techniques. Straightforwardly, more elaborated problem solving approaches are characterized not only by greater effectiveness, but also by major obstacles that practitioners have to overcome in order to use them proficiently.

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1.1. An insight into the use of TRIZ tools

Ilevbare and colleagues [4] show to which degree different TRIZ tools are employed by TRIZ enthusiasts. However, this picture does not necessarily correspond to a more general situation, in which to include the whole arena of designers who rely on TRIZ way of thinking to any extent. By using the names of the tools discussed in [4] as keywords for a web search in a scientific database, i.e. Scopus, the number of results obtained with Inventive Principles and Contradiction Matrix is, by no surprise, exceedingly greater than the residual ones. Besides, these two heuristics are naturally juxtaposed and, therefore, they are very likely to form the core of TRIZ knowledge within a very large number of scholars, engineers and practitioners.

Beyond the contents illustrated in basic TRIZ courses, their diffusion can be ascribed to their simplicity and flexibility. For instance, by supporting the choice of Inventive Principles as the most suitable technique to be implemented in a TRIZ-supported CAD system, León-Rovira and colleagues [5] highlight that this tool:

- is known by anyone who has the even smallest grasp of TRIZ;
- provides TRIZ outsiders with clear and intuitive suggestions.

As remarked above, these heuristics do not constitute the most reliable and rigorous set of techniques in the TRIZ toolkit. In particular, the utility of Contradiction Matrix is a controversial issue within TRIZ community. The harshest criticism is expressed in [6]; the Matrix is consequently considered as a shortcut for introducing people to TRIZ, convincing them of the effectiveness of the theory through a method leading to quick solutions [7]. On the contrary, some works report different results. For instance, Slocum and Domb [8] have tested the success rate and the innovation level when approaching the problem in terms of physical or technical contradictions. According to this experiment, both separation principles and the Contradiction Matrix are considered successful, being their performance almost equivalent.

Intermediate outcomes are shown by Mann [9], who shows that the Contradiction Matrix resulted useful in the 48% of treated case studies. From a wider perspective, which takes into account various kinds of industrial problems, the difference between success rates is remarkable, ranging from less than 10% (managements issues) to 80% (simple mechanics).

The fluctuating accuracy of the Matrix and the influence of the application field on it have led towards proposals of contradiction-independent ways of searching for principles [10, 11] and adaptations to specific technical disciplines [12].

However, with respect to the capability of facing complex problems, no proposal has been advanced up to now (at least according to authors' knowledge) to make the most diffused TRIZ tools evolve towards multi-contradiction schemes.

1.2. Alternative strategies to solve complex design problems

Thus, when problem solvers need to face intricate situations, they can opt to employ more advanced TRIZ tools or rely on different strategies. When possible, the intuitive choice of the main reference problem has not to be excluded [13].

In other cases, the selection of the most pressing problem to be solved is deliberately performed through the exploitation of non-TRIZ methods [14].

The literature of TRIZ is abundant in contributions that match Altshuller's theory with other design methods. A reference state-of-the-art analysis is [15]. The cited paper highlights how limitations in the proficient use of TRIZ arise in certain industrial fields, as the variable performance of the Matrix has already suggested. In the mare magnum of juxtaposed theories, the present paper is particularly concerned with approaches and techniques that allow to analyze a complex problem and deduce the most relevant conflicts.

In this sense, the combination with Axiomatic Design (AD) [16] results in being the most appropriate, since it can be employed to structure the problem in an appropriate way, so as to identify relevant conflicts. The approach followed by AD is useful for analyzing the system and its requirements, but it completely lacks means to identify technical solutions. These solutions, according to the axioms that guide AD users in the design process, should be conveniently characterized by satisfying performances for each requirement and high controllability of the system. In this sense, the combination of AD and TRIZ emerges as a valuable option, also thanks to the not contradictory objectives the two design methods set, at least at first sight.

1.3. Objectives and organization of the paper

The authors are currently paying research efforts to formulate new ways through which to implement TRIZ and AD-related bodies of knowledge, with the specific priority of supporting the undertaking of complex technical problems. In light of their experience, they believe that the trivial juxtaposition of AD indications to structure problems and basic TRIZ tools to remove contradictions is far from being efficient, especially as the complexity of the system grows. In a preceding study [17], which will be briefly exposed in Section 2, the authors have investigated the motivations behind the drop in number of scientific contributions devoted to illustrate case studies combining AD and TRIZ. In virtue of the analysis of the literature treating both theories contextually, [17] highlights a large number of open issues that have not been appropriately addressed by the design community.

Among the others, the suitability of the synergic use of TRIZ and AD with respect to different industrial contexts has not been discussed sufficiently. In order to fill this gap, the present paper shows a study (Section 3) on the technical disciplines in which TRIZ and AD are mainly exploited by practitioners. A more insightful investigation has been conducted for the industrial fields for which the diffusion of TRIZ and AD resulted in a particularly different intensity.

Eventually, Section 4 discusses the results of this research activity, while Section 5 puts forward authors' point of view with respect to the strategies to be adopted to match TRIZ and AD harmonically. The advanced proposals are open for discussion to the TRIZ Future Conference audience.

2. Previous research on the compatibility between TRIZ and Axiomatic Design

The beginning of 2000s has seen intense interest in the combined use of TRIZ and AD. The strengths of this matching were seen in the complementary design activities they support, by both addressing the goal of creating innovative products. With reference to complex systems, AD was deemed particularly effective in analyzing the problem in a systematic way. Indeed, the matrix format through which the system is described (Figure 1) performs the problem setting by linking design objectives (Functional Requirements, FRs) and the factors that influence them (Design Parameters, DPs). According to AD formalism, the matrix reports the symbol *X* when a DP impacts on a FR, *x* when there is a weak influence, *0* when no relationship takes place.

$$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X & X & 0 \\ X & X & X \\ x & 0 & X \end{bmatrix} \times \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix}$$

Fig. 1. Illustrative representation of a system analysis performed by means of Axiomatic Design.

AD axioms indicate that all situations in which a DP influence two or more FRs should be avoided in the improved solutions. From this perspective, there is a clear parallelism between DPs-FRs relationships in AD and the dependence among Control-Evaluation Parameters (CPs-EPs) in TRIZ contradictions.

Given these affinities, applications are presented in literature in which TRIZ has been implemented in the AD framework in order to provide means to devise proper solutions, since AD completely lacks strategies to stimulate inventiveness. Among the TRIZ problem solving instruments that had been integrated, the Contradiction Matrix and Inventive Principles stand out, being they deemed as simple and intuitive heuristics to overcome troublesome situations.

However, despite initial enthusiastic judgments about this design approach, the research efforts have rapidly waned that concern the conjoint use of AD and TRIZ, as anticipated in Section 1. The authors have analyzed the literature in order to provide a greater understanding of the unsatisfactory results of TRIZ-AD combination strategies. The following criticalities have been highlighted in [17]:

- the unsuitability of TRIZ to solve some kinds of problems emerging from AD analysis, e.g. when the structuring of the problem results in a triangular matrix;
- the different criteria that TRIZ and AD use to evaluate solutions; on the one hand, AD pursues functional independence, not unlikely through the introduction of new components; on the other hand, TRIZ chases after ideality, embodied in solutions whose materiality vanishes, but are still capable of delivering all the required functions;
- designers with an AD background usually seek for reducing the number of FRs to the minimum possible, while TRIZ forecasting tools urge users to develop products that are capable of fulfilling new benefits by increasing the ideality level;
- meaningful abstraction processes might be required to turn AD-defined problems into TRIZ contradictions, because of the different design aspects that are emphasized by the two methodologies;
- AD points out problems to be solved whenever a DP influences more than a FR (see grey cells in Fig. 1); TRIZ contradictions emerge only when a CP should assume different and incompatible values in order to fulfil the requested performances of two or more EPs.

The literature has thus shown a large number of theoretical limitations in terms of using AD and TRIZ contextually. Minor insights are available into the practical problems that can emerge in industry.

3. Industrial fields in which TRIZ and AD are commonly employed

In order to integrate the findings presented in Section 2, a survey has been judged necessary of the industrial contexts in which TRIZ and AD are mostly diffused. This sort of study is deemed relevant in terms of defining which kind of problems are more likely addressed by both the methodologies. A first attempt has been made in this sense: however, the reference work is quite dated and restricted to the manufacturing sector [18].

TRIZ and AD are claimed to guide design systematically for a variety of problems. However, we have seen in the previous sections how TRIZ performances are superior for mechanical problems. This observation is not surprising, if we consider the main fields analyzed by Altshuller as a patent officer, i.e. those related with military technologies, when inferring the limited number of principles to achieve inventive solutions. In order to grasp a preliminary understanding of AD, a simple case study concerning a faucet is usually illustrated to people who are exposed to the theory. Nevertheless, industrial applications are likely to appear in diversified fields.

3.1. Classification of the applications of TRIZ and AD

The first step of study regarded the selection of the sample of sources from which to extrapolate the fields of applications for the treated methodologies. In order to keep the focus on scientific works, the authors opted to gather Scopus-indexed articles discussing TRIZ and/or AD. In particular, the research was conducted by searching the terms “Axiomatic Design” and “TRIZ” in the title, abstract and keywords.

The objective deliberately consisted in analyzing just the most recent results, in order to point out the current domains of application with regard to TRIZ and AD. The study was conducted in June 2015. At that time, the number of available results published in 2015 was considered too limited for the scope of building sufficiently large sets of articles. Accordingly, manuscripts published in both 2014 and 2015 were taken into account.

The width of the sample can be deduced from Table 1.

Table 1. Classification of industrial applications of TRIZ and Axiomatic Design reported in Scopus-indexed articles published in 2014 and 2015.

Industrial field	TRIZ (#)	TRIZ (%)	AD (#)	AD (%)
Vehicles and vehicle's components	19	18.8%	3	4.7%
Chemistry and materials processing	11	10.9%	2	3.1%
Civil engineering	9	8.9%	2	3.1%
Manufacturing tools and systems	8	7.9%	7	10.9%
Energy	7	6.9%	6	9.4%
ICT and virtual environments	7	6.9%	5	7.8%
Mechanical components	7	6.9%	5	7.8%
Hydraulics and Fluid mechanics	7	6.9%	4	6.3%
Electronics and electric components	7	6.9%	3	4.7%
Healthcare	6	5.9%	4	6.3%
Appliances	6	5.9%	0	0.0%
Devices for disabled people	3	3.0%	2	3.1%
Agriculture and forestry	3	3.0%	0	0.0%
Management in industry	2	2.0%	7	10.9%
Robotics and Intelligent Manufacturing	2	2.0%	4	6.3%
Objects handling and conveyors	2	2.0%	3	4.7%
Services	2	2.0%	2	3.1%
Mining and extraction	2	2.0%	0	0.0%
Illumination	2	2.0%	0	0.0%
Breeding and fish farming	2	2.0%	0	0.0%
Food and beverages	2	2.0%	0	0.0%
Other	8	7.9%	4	6.3%
TOTAL	101	100.0%	64	100.0%

The following conditions were verified in order to include each gathered record in the study sample:

- the article was not only discussing the application of TRIZ and/or AD from a theoretical point of view, but it also shows at least a practical industrial application;
- the use of TRIZ and/or AD has resulted beneficial for the scopes of the treated design problem.

On the other hand, the following aspects were not considered:

- whether the methodology had been used by itself or in concert with other design techniques;
- whether the employed heuristics of the reference methodology belong to the traditional body of knowledge of TRIZ/AD or to extensions developed by scholars and/or practitioners, e.g. OTSM-TRIZ [19, 20] or Fuzzy Axiomatic Design [21].

Once all the relevant articles were gathered, the authors classified the applications of the methodologies according to an ad-hoc categorization of the industrial fields, also considering the absence of any internationally accepted schemes. Table 1 presents the results of the survey: the cluster “other”, at the bottom of the scheme, represents fields for which the number of applications of both TRIZ and AD resulted in being lower than 2. The other rows are arranged in order of decreasing quantity of TRIZ applications at a first instance and descending number of AD applications at a second instance.

For the sake of clarity, an appropriate clustering could not be carried out automatically; hence, the authors performed the classification manually. Indeed, the available categorization of the articles is based on the main topics of the sources in which they are published. Such a distinction was not suitable for the scopes of the paper in light of several motivations: the most relevant two are discussed. First, the standard classifications are too broad, e.g. “Engineering”, “Computer Science”: this distinction does not allow to define the field of application with sufficient detail, for instance it does not permit to discern managerial from mechanical or electrical problems. Second, many reference journals and conference proceedings are extremely general in their topics and, as a result, applications can concern any technical field.

3.2. Insights of the investigation

Table 1, with a specific reference to the percentages reported on the third and fifth column, shows an uneven distribution of the application fields if we compare TRIZ and AD. On the one hand, TRIZ prevails in industries that manufacture end products, showing a more intense diffusion within, e.g., vehicles, electronics and domestic appliances. On the other hand, AD is remarkably oriented to produce solutions that are not directly embodied in mass-market artifacts. Readers can notice greater diffusion of AD in fields like manufacturing tools, management and robotics.

A preliminary overview would suggest therefore that TRIZ is more useful in Business-to-Customer situations, while AD is mainly concerned with problems that directly affect enterprises. In order to strengthen these preliminary indications, the authors performed an insightful analysis of the contributions classified into the application fields showing major percentage differences. In particular, the authors surveyed whether the use of TRIZ was limited to the application of problem solving heuristics and the employment of AD concerned the formalization of systems’ structure. In this case, their matching could result advantageous.

3.3. TRIZ in vehicles and chemical industries

The application fields for which TRIZ prevailed AD most largely are “vehicles and vehicles’ components” and “chemistry and material processing”. The way TRIZ has been used in these fields was explored by investigating 30 articles.

While for some of them the way of applying TRIZ was not clear, a minority of industrial problems was overcome by means of trivial TRIZ heuristics (6 out of 30 cases). With reference to many case studies, the problem was not limited to the solution of a contradiction and more complex approaches were followed. Among the others, scholars exploited more sophisticated instruments belonging to the classical TRIZ body of knowledge in 7 cases. Even more frequently, the outreach of TRIZ was limited to problem solving and other methodologies were exploited to perform problem selection and decision making. It is worth mentioning the presence of Quality Function Deployment, Value Analysis and Brainstorming as the most diffused techniques that are combined with TRIZ in the examined sample. Besides, we can underline the employment of TRIZ as a forecasting instrument, rather than a toolkit for problem solving, in 2 cases out of 30.

3.4. AD in management and robotics

The two application domains for which AD prevailed TRIZ most largely are “management” and “robotics and Intelligent Manufacturing”. Surprisingly, the introduction of AD in these fields is not particularly aimed at structuring the problem. As described above, this capability is seen as the most promising AD support for engineering design tasks in terms of its combination with TRIZ, especially from the viewpoint of facing complex problems.

Just one out of the 11 applications belonging to the cited fields clearly employs AD in order to support problem definition. In many cases, AD is basically exploited to the purpose of optimizing solutions and tackling decision making. It is worth noting that 4 articles of this sample make reference to Fuzzy Axiomatic Design [21].

3.5. Fields relevant for both TRIZ and AD

According to these insights, industrial sectors that are relevant for both Business-to-Business and larger markets are, not surprisingly, populated by a not negligible number of TRIZ and AD applications. They include “Manufacturing tools and systems”, “Energy”, “ICT and virtual environments”. This does not mean that theoretical and practical problems that affect the mutual employment of the two treated methodologies do not apply in these domains. Supposedly, such industrial fields require holistic analyses of the systems, inventive problem solving and optimization procedures to a significant extent. In each case, these industrial sectors represent the most promising field of application of refined tools that include both TRIZ and AD way of approaching design problems.

4. Discussion of the outcomes of the investigation

The paper has presented an investigation into the ways and the domains in which TRIZ and AD are applied in the most recent scientific contributions. The analysis has been performed because the authors are willing to fine-tune new approaches capable of blending the powerful capabilities of both the methodologies. However, the illustrated results can be exploited by any scientist interested in exploring actual trends of engineering design methods. More detailed information about the outcomes of the analysis, e.g. the list of references belonging to each application field, can be requested to the corresponding author.

Despite some positive results obtained also in the last few years [22], the classical scheme of system analysis with AD and problem solving with TRIZ basic tools has demonstrated to be far from suitable for industrial scopes. The recalled drop in number of scientific contributions that combine TRIZ and AD reveals the current skepticism about their use in concert.

In this sense, the paper provides additional insights to elucidate the reasons of unsuccessful matching. The previous authors’ work has reviewed the theoretical problems whose overlooking has produced poorly robust combinations of AD and TRIZ. The present paper sheds light on further divergences, which concern the preferred application fields and the objectives of their application.

It emerges that TRIZ has the propensity to work adequately in the design of end products or other deliverables that address the mass market. TRIZ contribution is currently not limited to the employment of the most known problem solving techniques, such as Contradiction Matrix and Inventive Principles. On the contrary, at least in the fields for which AD results poorly diffused, its toolkit is adapted to face more articulated contradictions, as well as TRIZ is combined with other theories in order to approach the problem from requirements definition and prioritization to the convergent phase of conceptual design. The use of TRIZ as a forecasting discipline is not negligible.

The trajectory drawn by TRIZ does not intersect the trends in AD that have been deduced through the present study. Indeed, AD hardly outreaches the domain of problems, services and systems that impact on the Business-to-Business world exclusively. Furthermore, the principles descending from axioms are mainly exploited to the scope of optimization and decision-making.

Hence, we can infer that the above trajectories shaped by TRIZ and AD have largely contributed to their decreasing mutual implementation. This aspect cannot be overlooked by scholars willing to thrust into the obstacles of developing new ways to use TRIZ and AD in a synergic manner.

5. Authors’ view about future development opportunities

In virtue of the outcomes of the present investigation and the findings presented in [17], the authors provide their interpretation about the future opportunities of proficiently blending TRIZ- and AD- way of thinking and tools into new design strategies and methodologies. According to their understanding, the most relevant considerations that affect the success of future methodological combinations are the following:

- the classical framework that foresees the sequential use of AD (for problem analysis) and TRIZ (for solving circumstantiated contradictions) is not effective; the capabilities of both methodologies cannot be exploited unless their toolkit is integrated appropriately, especially in the case of complex systems to be tackled;

- the tendencies about the use of TRIZ and AD remark how both disciplines are best applied in specific industrial sectors, as well as the objectives of their employment are crossing their traditional borders, e.g. TRIZ as a forecasting tool and AD for optimization purposes;
- TRIZ/AD criteria (e.g. ideality/independence) can be suitably employed to evaluate solutions driven by AD/TRIZ, as well as these concepts can be blended suitably in engineering design tasks (preliminary attempts are documented in [24].

From this standpoint, the authors see, at first, the opportunity of building a new framework to support product development, capable of addressing problems related to complex systems. The performed review has shown how current practitioners have become accustomed to employing sophisticated TRIZ-based tools. According to this remark, it is possible to fulfil easily the need for cutting across the sample of TRIZ techniques that have been commonly juxtaposed to AD up to now. In particular, the first expected step is to translate the mapping of dependences among parameters, as it emerges from AD, into a general frame of the conflicts that are inherent to the given technical system. The Network of Contradictions [19, 23] is a good candidate, since it allows to schematize the full range of problems affecting a technical system. The guided resolution of contradictions, releasing mutual cause-effect relations among parameters and requirements can lead to update AD matrix dynamically, encouraging the problem solver to persevere until a decoupled or uncoupled scheme is built, hence a controllable and well-performing solution is designed. Favorite TRIZ techniques are those that help find configurations in which relationships between parameters are overcome, rather than alleviating the magnitude of the contradiction. Otherwise, from an AD perspective, the technical system would be improved, but the independence axiom would be neglected. In other terms, a *X* relationship would be just turned into a *x* dependence situation, which does not satisfy AD axioms completely.

Still in light of author's view, another opportunity is represented by exploiting TRIZ forecasting capabilities to shape new requirements for product development tasks; in this sense, TRIZ concepts have been exploited e.g. in [25]. On the other hand, the fulfilment of needs deliberately ranges among the goals of AD.

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