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Adapted Use of the TRIZ System Operator

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Abstract: The System Operator (SO), also known as Nine Boxes or Multiscreen, is classically used for analysing the undesired situation according to different perspectives. However, its logic can be suitably exploited also for other kinds of tasks. In such a context, this paper shows an alternative application of the SO. In particular, the new proposed SO approach allows us to formulate alternative problems, i.e., different from the central one, although referring to the same problem-solving task. By applying the proposed procedure to a real case study, this paper shows that the tool can be used for problem analysis and formulation purposes, aimed at better clarifying the problem-solving task. The case study concerns a preliminary set of experiments performed to evaluate the possibility of obtaining angular shapes by bending tiles made by a specific compostable composite material. The suggestions obtained using the proposed SO approach allowed us to find potentially valid solutions, thus paving the way for further validation tests. In particular, tests are still needed to validate the actual potentialities of the proposed SO. Additionally, further and more comprehensive tests are required to validate the solutions inferred in this study concerning the compostable tiles.

Keywords: TRIZ; packaging; problem solving; System Operator; Multiscreen

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1. Introduction

TRIZ is nowadays one of the most acknowledged bases of knowledge for problem solving, mentioned in several literature contributions. The acronym TRIZ stands for 'Teoriya Resheniya Izobretatelskikh Zadach', often translated in English as the 'theory of the resolution of inventive problems'. TRIZ offers a set of tools to be conveniently selected according to specific needs [1]. It was formerly developed by Genrich Altshuller [2], whose first publication (*On the Psychology of Inventive Creativity* [3]) dates back to 1956 and argues about how to solve thousands of different technical contradictions by means of a limited number of 'inventive principles'. It is also worth noticing that several classical TRIZ developments and/or alternatives arose during the years (e.g., SIT [4], USIT [5], CROST [6], etc.). Providing descriptions of these contributions falls out of the scope of this paper. However, the main observations originally made by Altshuller can be summarised in the following three points [1,7]:

- Technical systems evolve according to objective laws, towards an increasing degree of ideality (i.e., the ratio between benefits and the sum of costs, intended as resource consumption, and harmful effects).
- Any specific technical problem can be converted into a more general one through an abstraction process. Thanks to the abstraction, Altshuller observed that similar problems arise in very different fields, allowing the related solving processes to be grouped in a finite number of 'solving principles'.

- Given a finite number of standardised problems and solving principles, solutions based on similar concepts can be used for solving apparently different technical problems.

The diffusion of TRIZ actually started after the fall of the Soviet regime. Indeed, many collaborators of Altshuller started to work in North America, Europe, and East Asia. Consequently, TRIZ is now taught in universities and adopted by well-known companies across 35 countries [8]. In particular, some big industry corporations immediately acknowledged its benefits [9]. Among them, Samsung represents one of the best experiences of TRIZ adoption in the industry [10,11].

The potentialities of TRIZ have been also scientifically observed by performing evaluations and tests through academic students (e.g., Hernandez et al. [12], Borgianni et al. [13]). Moreover, scholars have performed investigations on the actual use of TRIZ tools within the industry (Moherle [14], Ilevbare et al. [8]), substantially observing that only a limited and not univocally defined set of TRIZ tools are usually considered by practitioners, among those available. Furthermore, several studies propose to exploit TRIZ, and/or some of its fundamentals for different design-related purposes (e.g., [15–18]). These lines of evidence show that, despite the potentialities, the actual use of TRIZ tools is far from standardisation. Additionally, although some structured procedures can be used to select the most suited tool, it is worth noticing that the selection of the tools strongly depends on the skills of the user, who should be well trained for ensuring a correct application (e.g., [19]).

For this work, the authors considered the tool named 'System Operator' (hereinafter called SO). The SO is a 3 × 3 (or even larger) matrix which allows the translation of the problem formulated in the central box into eight different forms. It is also known as 'Nine Boxes', 'Nine Windows', or simply 'Multiscreen' operator, and is one of the most acknowledged TRIZ tools [8]. According to Figure 1, the rows allow focusing the attention on different resources potentially available outside the system, in the system itself, and in the subparts of the system. More specifically, the central row of SO represents the system, the bottom row represents the parts constituting the system (i.e., subsystems), while the upper row represents the elements of the environment to which the system belongs or all other systems with which the system can interact (i.e., supersystem). Differently, the columns represent the time dimension, i.e., the central column of the matrix represents the present, the left column represents the past, and the right column represents the future.

What can be done

	Before the problem appears	When the problem appears	After the problem appeared
Outside the system			
To the system			
Within the system			

Figure 1. Illustrative representation of the System Operator [20,21].

Gadd [20] asserts that the SO can be used in many different ways and provides numerous examples to show that the tool can actually suggest different triggers and stimuli to support problem solving. Although the SO is used to support the exploration of possible solutions, all the boxes point to the same original problem. A slightly different interpretation is suggested by Orloff [6], who shows how new ideas can be achieved by investigating the temporal evolution of the problem formulated in the central box, as well as its different levels of detail. However, also in this case, the SO still refers to the main problem formulated in the central box. Other literature contributions (e.g., [22–24]) confirm that, notwithstanding the versatile nature of the SO, it is generally used by pointing to the same original problem.

With regard to the above-introduced concept, the objective of this work is twofold, as explained in the following.

The first aim concerns a contribution to the TRIZ theory, in that the authors are interested in studying and testing an alternative way to use the SO. Indeed, while the potential advantages of the classical SO approach are widely acknowledged among TRIZ researchers and practitioners, there is no official documentation about the other potential uses. In this paper, a specific alternative use of the SO is considered with the aim of providing first-hand information about the related potentialities.

The second aim is linked to the first and refers to the ongoing activities regarding the development of an innovative and sustainable composite material for the production of tertiary packaging, which is named NeoPalea [25]. In particular, the authors address the manufacturing of prototypes constituted by straw and the biodegradable plastic Mater-Bi®. The straw is a waste by-product of cereal production, which is characterised by a very limited market value, while Mater-Bi is a biodegradable and compostable bioplastic produced from corn starch by Novamont S.p.A (Novara, Italy).

The experiments performed in this work aim to conduct preliminary tests on the material by following the suggestions generated by the use of the SO. In this way, the authors obtained, on the one hand, relevant outcomes to check the potentialities of an alternative use of the SO, and, on the other hand, insights about future developments for manufacturing packaging solutions using NeoPalea.

2. Materials and Methods

2.1. How the System Operator Has Been Used

2.1.1. Classical Approach

To the best of the authors' knowledge, the most diffused use of the SO concerns the search of resources potentially useful to solve a specific problem (i.e., the problem formulated in the central box of the SO). This procedure is inspired by the work of Altshuller [26], who highlighted the differences between an 'ordinary' inventor and an 'extraordinary' inventor. More specifically, the latter has the capability to explore both the super-system and the subsystem levels, in addition to the system level. Furthermore, the extraordinary inventor can also keep track of the evolution of the problem (i.e., past, present, and future).

In its classic use, the SO is then a 3×3 matrix to explore the resources that can be potentially exploited to solve the problem expressed in the central box. Therefore, the user should start by defining what actually represents the system and the present, i.e., the central box of the matrix. Subsequently, according to what is expressed in the central box, it is possible to identify the supersystem, i.e., those resources that can potentially interact with the system, or that constitute the surrounding environment where the system actually works. Similarly, the user should identify the subsystem, i.e., the set of parts and/or subassemblies that constitute the system. The central column of the SO is then compiled (see Figure 1 as a reference). Different strategies can be followed concerning the left and right columns, depending on the specific problem and the related context. Indeed, the 'time scale' can assume different meanings, e.g., related to the life cycle of the system, or the past–present–future related to a specific action (i.e., before the action is performed (past), during the action (present), or after the action is performed (future)). Moreover, the amount of time characterising the chronological leap among the different columns is not constant but can vary according to the specific case (e.g., it could be 1 min, one month, or even years). Altshuller considered another SO dimension also, i.e., that of the antisystem [26]. However, this further dimension was not considered in this paper.

In the following, an example is reported showing how to build the SO (Figure 2). In the text, a generic problem (i.e., the cutting of the weed in a domestic garden) is considered to ease the understanding of the approach.

	Define the Past	Present (identified by the central box)	Define the Future
Supersystem		Identify the supersystem	
System		START: identify the system at the present state	
Subsystem		Identify the subsystem	

Figure 2. Questions to guide the construction of the SO.

The first step is the identification of the system at the present state (e.g., the grass to be cut). Then, it is necessary to identify the supersystem (e.g., the garden, the plants, the furniture, as well as the sun, the atmosphere, the weather, the cutting system, the gardener, etc.). Additionally, the subsystem must be identified (e.g., the specific type of grass, the physical characteristics of every single strand of weed, etc.).

It is necessary to select the most appropriate strategy for defining the time scale, according to the specific task. A possible option is considering the life cycle of the system, (e.g., the seeds, the first sprouts, then the grown weed up to the dead grass). Alternatively, past and future refer, respectively to 'before' and 'after' the action performed in the present (e.g., the cut of the weed). Accordingly, the SO represented in Figure 2 is obtained.

What characterises the classical approach is the 'resources' listed in each box of the matrix, which can conveniently be used to stimulate the designer in finding possible solutions to the central problem. Therefore, in each cell of both the future and the past columns, it is necessary to identify the specific potential resources (e.g., the grass before the cut in the 'past system' cell or grass roots in the 'past subsystem' cell). The classic SO for the 'weed example' is reported in Appendix A.

2.1.2. Proposed Approach

In the approach proposed and tested herein, the construction of the SO starts from the initial problem, which, as for the classical approach, constitutes the central box of the matrix. The initial problem allows the 'present' column to be identified, both from the causal and chronological perspectives.

The problem is expressed in the form of the question 'What can the system accomplish for . . . ?', and in the same central box, it is necessary to specify what actually is the system. Usually, the object of the function representing the problem or the technical system can be considered as a 'system'.

Then, it is possible to formulate the other boxes of the same column by following the same rules of the classical approach, i.e., by listing the elements or resources available in the supersystem and the subsystem. However, it is also necessary to formulate the problems for both supersystem and subsystem with the proposed approach. These problems are expressed in the form 'What can the element of the super/subsystem accomplish to support the resolution of the central problem?'

In other words, in the boxes of the same central column, the main problem is the same, but the resources that can potentially contribute to solving it are different.

In order to formulate the column of the 'past', it is necessary to identify the causes that lead to the central problem. For this, the user can take advantage of simple questions such as 'Why do we need to solve the central problem?', 'Why does the central problem appear?', or 'What is the cause that leads to the central problem?' The answers to these questions can be used as problems to be inserted in the system–past box. Then, the boxes related to the super- and subsystems are formulated with the same procedure used in the column of the present. Then, each problem is transformed into a question.

The same process (from the present to the past) can be iterated several times, thus allowing to obtain different columns of the past (let us say different past levels), until the problems are reasonably related to the main task.

It is not required to provide an answer to all questions. Questions are intended only to push the designer to reflect on alternative and potentially more effective formulations of the problem.

To formulate the problem in the system–future box, it is necessary to refer to the undesired effects coming from the nonresolution of the central problem. Therefore, when moving to the column of the future, the user assumes that it is necessary to accept the problem and to eliminate or reduce the related undesired effects. The other boxes are then formulated by following the same process used in the present and past columns. As for the past column, many different 'future levels' can be considered, and then different columns of the future can be generated.

When the SO is compiled, it is possible to select the problem to be addressed. However, it is worth noticing that even if the problems are somehow related to the central problem, it does not mean that the related solutions can directly solve the central problem. For example, by solving a problem in the column of the past, the user allows preventing the rising of the central problem. Differently, by solving a problem in the column of the future, the user mitigates the negative effects that come from the nonresolution of the central problem.

For the selection of the problem, there is no specific rule. The user can select the problems in relation to the available resources, the know-how, or simply by following the rationale 'prevention is better than cure'.

Once the problem is selected, the user can follow the classical solving procedure.

By considering the same example of Section 2.1.1, the SO presented in Appendix B was obtained, as well as the specific procedure used for the construction.

The case study introduced in Section 3 is a more structured example, which allows a better understanding of the differences between the classical SO and the proposed one.

2.2. Experimental Set-Up for the Preliminary Tests on the NeoPalea Panels

2.2.1. Preparation of Panels

As shown in Figure 3, the experimental forming cycle of NeoPalea panels began with a plurality of straw bundles arranged in parallel with each bundle wrapped in a sheet of Mater-Bi to form elementary cylinders. The cylinders were then inserted into a specific mould with a moving lid allowing us to compress the material vertically. The cylinders (whose diameter ranges from 30 mm to 40 mm) had to be in a sufficient number to fill the mould and be arranged vertically, i.e., in the same movement direction of the compression force. When the fibres of the straw are compressed, they are free to disperse chaotically in all directions.

By referring to the process shown in Figure 3, in this work, a manual press machine was used to compress the moving lid into the mould. Once the lid reached the desired position (i.e., the desired compression of the material), self-threading screws were used to lock it in that position. Then, with the cover/piston maintained in the final position and therefore with the fibrous material in a state of compression, the process entailed a heating phase up to approximately 80 °C, carried out by high-frequency electromagnetic radiation generators (about 2500 MHz with a power of 750 W) for a time ranging from 300 s to 900 s in order to achieve a complete blending of the bioplastic material and hence its bonding to the fibrous organic material. The obtained experimental prototypes are panels which have different sizes.

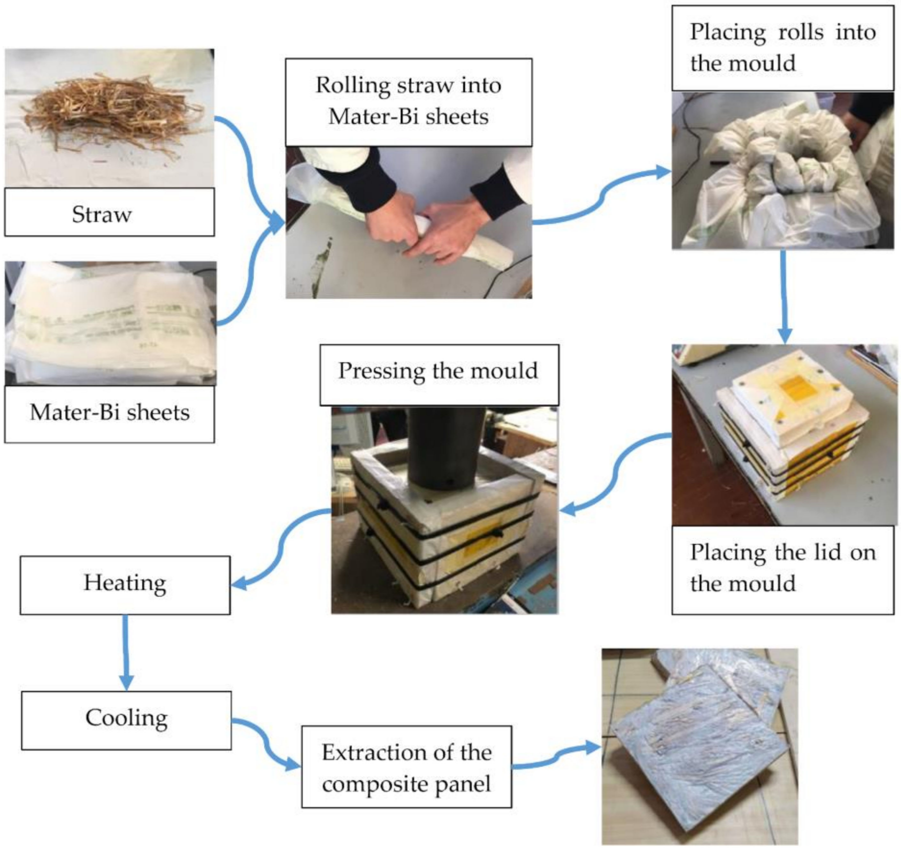

Figure 3. The NeoPalea forming procedure [25].

2.2.2. Testing Procedure

The experiment consisted of testing different shapes in different bending conditions in order to find suitable configurations to be considered for packaging manufacturing.

The bending of planar NeoPalea panels was hypothesised as a possible solution that could allow efficient industrialisation of the packaging production process. Indeed, the production of planar shapes could be obtained with continuous processes with relatively simple and then cheap moulds. Bending planar panels in order to obtain different packaging shapes allows reaching high form variety with low costs. Indeed, it is possible to directly obtain more complex shapes by using suitable moulds. However, such moulds are more complex and more expensive. Additionally, different moulds are required to obtain different shapes. This is why the main assumption was that the packaging product (or part of it) can be obtained by forming prefabricated NeoPalea panels.

The problem with bending planar NeoPalea panels resides in the need to verify the actual capability of the material to reach angular shapes and to maintain them.

To perform first investigations on the bending of the panels, a wooden punch–die system, with an angle of 90° (see Figure 4), was used.

The testing process composed of the following simple steps:

1. Placing the panel on the wooden die;
2. Bending the panel with the punch (moved by the same press used in the process depicted in Figure 2);
3. Measuring the compression magnitude (in order to ensure the same value of 0.2 tons in each trial);
4. Maintaining the punch in position;
5. Extracting the bent panel (which encounters a partial springback);
6. Evaluation of the residual deformation and the possible criticalities.

The compression magnitude was measured by the manometer available on the press, while the evaluation of the residual deformation was qualitative. Indeed, the performed preliminary tests only aimed at finding the most important criticalities and related potential solutions.

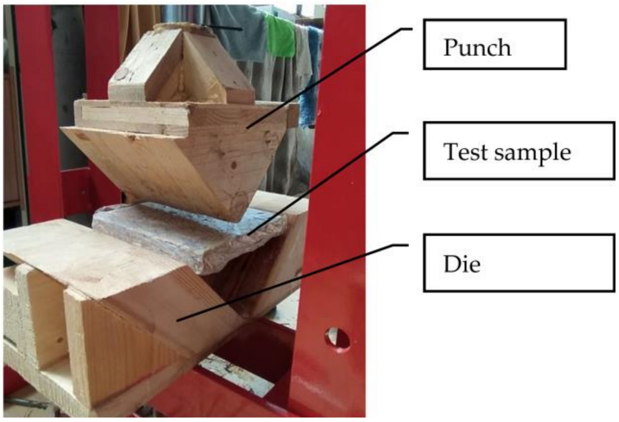

Figure 4. The punch–die system used to perform the bending tests.

3. Case Study Application: The Compostable Panels

3.1. Hints Provided by the System Operator Tool

3.1.1. Hints from the Classical Use of the SO

The first SO was built by following the classical approach explained in Section 2. It focused on the production of composite cylinders made of MaterBi and straws. The central box contained the core problem, while the other boxes were filled with some solutions directions generated after investigating the available resources.

In particular, to improve the production of the cylinders during their fabrication (i.e., the central column of the SO), a procedure to dose the straw was implemented considering the subsystem resources (straw and MaterBi). In addition, since the MaterBi sheets were very thin, a smarter way to supply the related sheets could ease the process. At the supersystem level, possible solutions were identified at the supersystem level by considering the introduction of a forming jig to speed up the cylinders' manufacturing. Alternatively, the usage of thermal welding was considered to avoid the undesired opening of the straw–MaterBi cylinders.

In terms of the column of the past, the time before the production and the related resources were explored. At the system level, the idea of performing a MaterBi pocket only to be later filled up with straw was found. Considering the supersystem, it was thought to analyse the state of the art relating to existing technologies that implement similar functions, while before the production, at the subsystem level, the hypothesis of solutions could be that of preordering the straw or cutting to size the MaterBi sheets. In the right column, that of the future, the temporal phases of the postproduction, i.e., once the cylinders were formed and produced, were considered. As reported in Figure 5, at the system level, it was inferred to build cylinder clusters that are easier to manage, both in terms of movement and filling of the mould (the supersystem direction of solution). Differently, the aspect considered at the subsystem level refers to the integrity of the cylinders that must be ensured until they are disposed into the mould.

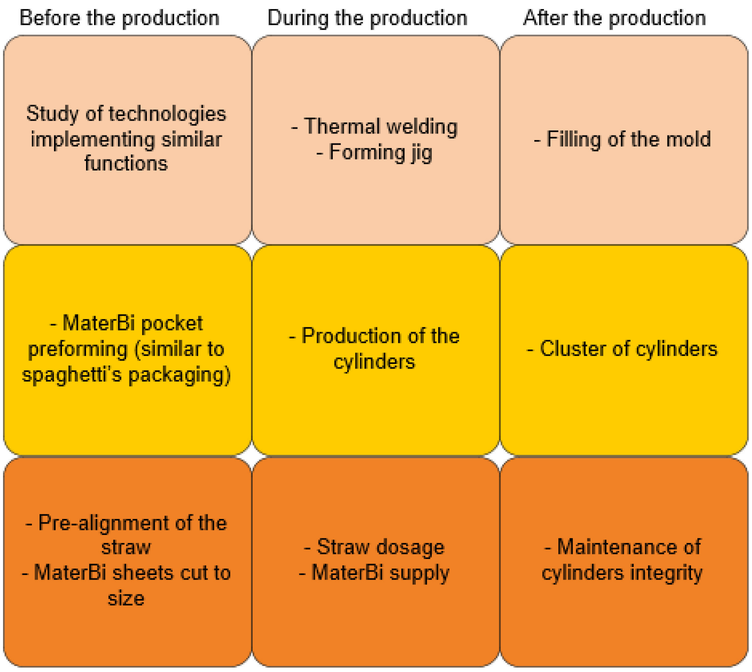

Figure 5. Hints obtained from the classic SO approach.

3.1.2. Hints from the Alternative Use of the SO

According to the rules explained in Section 2.1.2, two SO were built. The first addressed the problem of the cylinders' production, while the second related to the tiles bending.

Referring to Figure 6, the starting problem was introduced in the central box in the form of a question ('How can the system make the cylinders?'), also identifying the related resources for that level of detail (straw and MaterBi). After setting the system, the resources in super- and subsystems were listed, and the related problems were defined, which appear similar to the central problem but have different subjects depending on the level. Then, the authors proceeded with the compilation of the column of the past by referring to the question 'What is the cause that leads to the problem of the production of cylinders?' The answer is 'the need for a straw and MaterBi composite'. Therefore, when transposed into the formalism of the SO, it becomes 'How can the system make the composite straw + MaterBi without pre-formed cylinders?' The same question was repeated in the other two levels (super- and subsystem). However, this path could not be followed because the NeoPalea patent explicitly refers to a material made by closed cells. Therefore, any other solution hypothesis could not be taken into consideration. For this reason, the column of the past was discarded (grey column in Figure 6). As for the column of the future, by considering the problem of the present not solved, the resulting undesirable effect is that the cylinders would not be available, and therefore, the required closed boxes in the composite material would be missing. Therefore, the characteristic problem of the column of the future is 'How can the system make closed boxes (Claim # 2 of the patent) to fill the mould?'

Even if this new interpretation of the SO was believed to support the analysis phase, allowing alternative problem formulations to be found, the questions formulated in the SO boxes could help in identifying completely new solution directions. This can also be accomplished without applying the complete problem-solving process suggested by TRIZ but by simply relying on intuition or a brainstorming process supported by this tool. Here, some of the solutions obtained by trying to answer the questions of the SO are presented as follows: from the supersystem–present, 'How can an element of the supersystem make the cylinders?' It is possible to consider the cigarette production machine, which works continuously and whose product has many similarities with cylinders (MaterBi instead of paper and straw instead of tobacco) or the rotating ring wrapping machines.

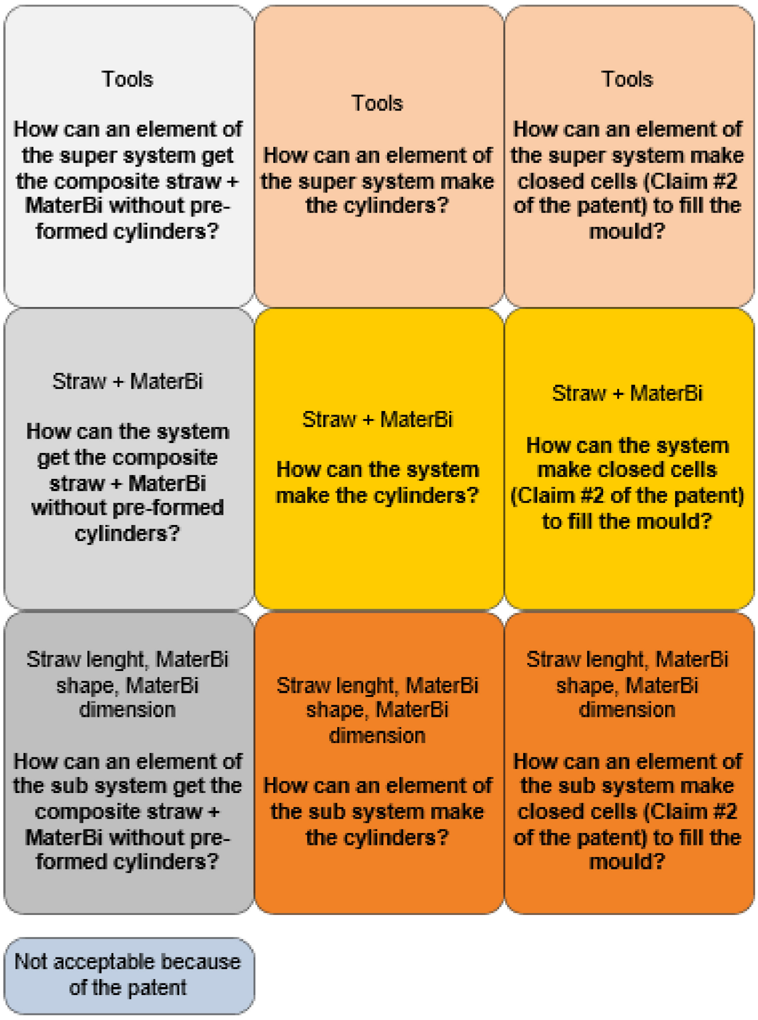

Figure 6. The first SO built for the case study by following the proposed alternative approach.

For the box of the subsystem–present, it was imagined to create a single but very long cylinder, to be cut to the desired size in a subsequent process phase. Instead, responding to the question of the system–future, a method of manufacturing closed boxes was ideated, leading to the creation of straw and MaterBi pads.

Following the same logic of the previous SO, another one related to the problem of the tile folding was built (see Figure 7). As usual, the main problem was entered in the central box, defining the tiles as the element representing the system–present. After a quick analysis of the resources, the super- and subsystem boxes were also completed. Then, by answering the question 'Why should the tiles be bent?', the problem in the past was formulated. The answer is 'because they are flat'. Therefore, the problem in the system–past translated into the correct formalism became 'How can the system achieve the desired shape in advance?' To define the problem of the future, the nonresolution of the present problem had to be considered (i.e., the tiles are not bent) as well as the resulting undesirable effect (i.e., the packaging box cannot be manufactured). Therefore, the problem of the system–future becomes 'How can the system make a box without bending tiles?'

As previously described, the questions raised by the SO were answered in order to find new solution directions. For the supersystem–past, it was decided not to mould the tiles but to modify the initial mould to obtain the box directly starting from the cylinders in order to avoid an intermediate step in the production process. The subsystem–present led to two different solutions: the first was to create a recess on the tile to weaken the bending area and reduce the backlash. The second solution concerned the heating of the tile before being inserted into the bending system to melt the bioplastic matrix again and then letting it cool in the die itself to make the assumed shape definitive. Two solutions also emerged from the column of the future. The first, from the supersystem, involved the creation of a box by gluing several flat tiles with compostable glue. The second instead derived from the subsystem and consisted of making joints on the tiles that then allow them to be assembled for the composition of the box.

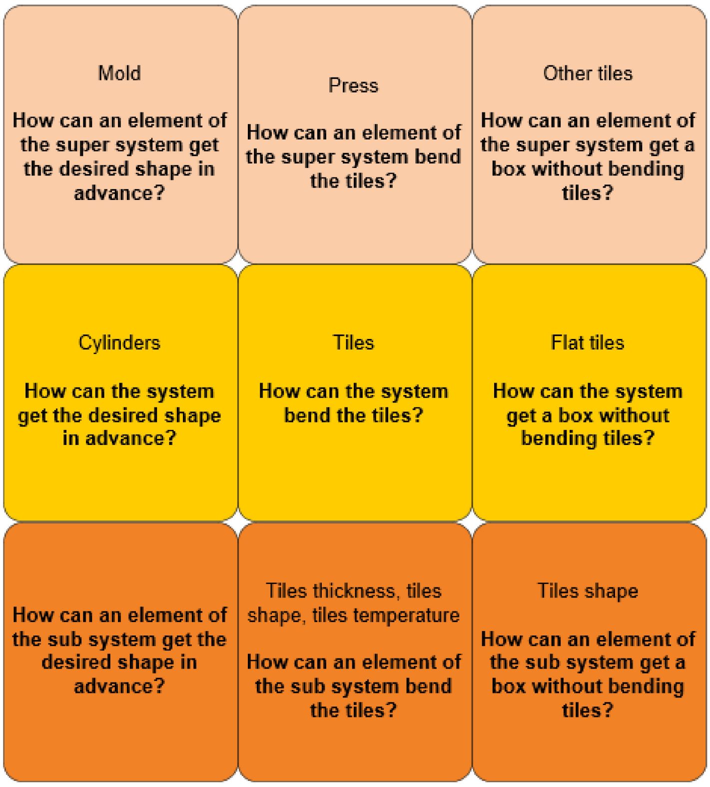

Figure 7. The second SO built for the case study by following the proposed alternative approach.

3.2. Experimental Results

The first trial was performed without any treatment of the tile. Unfortunately, the elastic backlash of the material was very high, as shown in Figure 8. Once removed from the die, the tile returned almost flat.

Figure 8. Bending results in normal conditions.

Then, by following the suggestions from the SO, a trial was performed by preheating the tile in the microwave oven, up to a temperature of 80 °C. In order to allow the cooling of the tile in the die, a time of 5 min was considered.

As shown in Figure 9, the results are sensibly improved, but a residual elastic backlash is still present.

Figure 9. Bending results with pre-heating conditions.

In order to reduce the backlash effect, another suggestion from the SO was considered, i.e., that of reducing the thickness in the bending zone (see Figure 10). It was possible to obtain the groove during the same tile formation process by adding a stick (triangular section) on the inner side of the lid.

Figure 10. Central groove created to ease the bending process.

The obtained results are shown in Figure 11, in which it is possible to observe that the backlash effect is sensibly reduced, compared with Figure 9. However, it is still present, and the tile tends to break the external MaterBi foil.

Figure 11. Bending results with preheating conditions and central groove.

4. Discussion

4.1. Obtained Results

4.1.1. About the Proposed Use of the System Operator

The suggestions obtained from the proposed use of the SO led to useful solutions for the considered case study. Although it is not possible to extract a general validation of the approach, this is the first evidence about the possibility of using the SO in the proposed way. This evidence is in a way a demonstration of what was asserted by Gadd [20], i.e., that the SO can be used in many different ways. In particular, the work presented in this paper demonstrates that the SO can be used to identify alternative problems, and the alternative solving directions, that can be used to support the solution of the central problem. In addition, this paper also shows that different SO approaches can be used in parallel, to find both resources and potential solutions to be exploited for solving the main problem.

As described in Section 2 and shown in Section 3, the main advantage of the proposed approach in relation to the classical one is the possibility to consider multiple problem formulations and then to potentially enhance resources exploitation.

Thus, the proposed approach paves the way for a comprehensive understanding of the possible different ways to use the SO.

4.1.2. About the NeoPalea Panels for Packaging Applications

The preliminary experiments performed on the NeoPalea tiles showed that it could be possible to bend them to obtain angular shapes. It is a very important result because the production of NeoPalea panels is surely easier and more sustainable than other processes (e.g., moulds with the final form of the package), and allows the process to be standardised. Indeed, the panels can be cut and bent to obtain different sizes of packages by starting from the same standard panel. In addition, the suggestion from the SO about the possibility of gluing different elements together paves the way for a hypothetical process in which angular shapes and flat panels are glued together to form the packaging box.

Other trials were also performed by reducing the thickness of the tile. In this way, the percentage of the bioplastic for each tile increases, and by following the bending procedure with preheating, the backlash effect is almost removed. However, this solution was discarded because the higher quantity of MaterBi led the tile to be too expensive, compared with the considered ones. Additionally, a reduced thickness led to tiles with quite rigid consistency, while for packaging purposes, a soft consistency is surely preferable.

Therefore, considering the results obtained in Section 3, it is possible to conclude that although it is possible to obtain angular shapes from a flat panel, some expedients should be considered when implementing the process. First, it is necessary to consider a die angle with extra bending to compensate for the backlash. Then, it is necessary to preheat the panel to be bent, and to carry that out, it is fundamental to identify the minimum temperature required to optimise the energetic consumption of the process and the time required to cool the panel before the extraction. Finally, it is important to consider that although the groove in the tile can lead to better results, it is necessary to identify the dimensions of the packaging boxes to be realised. This is necessary to understand if it is possible to obtain all the required shapes from the same standard panel.

4.2. Limitations and Future Developments

Many limits can be ascribed to this work. First, concerning the proposed SO approach, it is necessary to test it in order to verify the actual potentialities in providing useful and creative hints. To that purpose, standard experimental procedures are acknowledged in the literature, which could conveniently be used for that purpose. For example, the well-known set of metrics proposed by Shah et al. can be used [27], as well as the creativity assessment technique proposed by Amabile [28]. In particular, it is possible to focus the attention on two types of creativity, depending on the specific type of novelty. More precisely, it is possible to investigate if and to what extent the proposed SO approach can stimulate designers to generate ideas 'new in relation to their personal knowledge', i.e., the so-called 'psychological creativity' [29]. In this case, the a posteriori novelty metric of Shah can be used by considering the recent observations and improvements [30–32].

It is also possible to investigate if and to what extent the proposed SO approach allows researchers to find ideas that can be considered 'new in history'. This kind of creativity is called 'historical creativity' [29]. In this case, other approaches could be used, such as that proposed by Sarkar and Chakrabarti [33] and further refined by Jagtap [34].

This kind of investigation could support the understanding of the cognitive mechanisms that can lead the designer to a specific solution by starting from different kinds of stimuli. This topic is still very debated in design creativity research. However, if readers are interested in knowing more about how to obtain solutions from the proposed approach, they should note that the current literature (especially about the understanding of TRIZ) does not provide any robust answer about that. Accordingly, both the classical and the proposed SO approaches should be used to support the identification of potential 'stimuli' that can trigger the idea generation.

Concerning the NeoPalea tests, as declared in Section 1, they should be considered preliminary investigations about the feasibility of the bending process of the tiles. Accordingly, the obtained results should be considered only the first confirmation about the possibility of following that process, which needs to be confirmed in more structured experiments. Indeed, it is necessary to test different temperatures, different bending angles, different thicknesses, etc.

4.3. Expected Impact

The proposed SO approach can be considered by TRIZ practitioners and scholars, who can now refer to this paper to use the SO to formulate roundabout problems. Additionally, this new proposed approach can potentially pave the way for the development of a research stream devoted to the investigation of the different uses of SO in the different design phases. This simple way to use the SO to generate idea generation stimuli can also be interesting for scholars involved in studies about design fixation, i.e., the counterproductive and unconscious adherence to some solutions (e.g., [35–37]). Indeed, it would be interesting to understand if and to what extent the SO (both in the classical and the new versions) can be used to overcome design fixation. This should be a natural consequence of being a TRIZ tool since TRIZ is claimed to overcome psychological inertia.

The impact expected from the experiments performed on tiles is to indicate a possible way to exploit NeoPalea to produce packaging. This possibility is related to the need to reduce plastic use in the world, being plastic one of the most impacting pollution issues for our planet. Indeed, a significant quantity of packaging is still made from plastic, due to the still incomparable ease of manufacturing. Therefore, identifying an easy-to-manufacture way to obtain packaging from NeoPalea is of overwhelming importance to increase the possibilities of exploiting such an innovative compostable material.

5. Conclusions

The work described in this paper aims at presenting an alternative use of the TRIZ System Operator tool (identified with SO in the precedent sections) by applying it to a specific case study. The case study concerned the preliminary bending tests of compostable tiles obtained from the compression of cylinders made by straw and bioplastic sheets.

Both the classic and the new SO approaches have been described in this work and then applied to the considered case study. In particular, the main steps needed to build the two SO versions have been comprehensively explained in order to allow the reader to identify both analogies and differences.

The new version of the SO provided useful hints to formulate potential solutions for the problem related to the bending of the tiles. In particular, it is observed that the backlash effect is drastically reduced (even if not eliminated) by preheating the tile and by realising a groove along the bending line of the tile.

The obtained results, although preliminary in their nature, allow the indication of the proposed SO approach as one of the potential alternatives to the standard approach, capable of formulating roundabout problems and finding alternative solution paths.

As regards the preliminary experiments performed on the compostable tiles, it is observed that it is actually possible to obtain angular shapes from planar panels. It allows considering the production of NeoPalea standardised panels to be successively cut and bent. This process is surely easier and more sustainable than other alternatives (e.g., moulds with the final form of the package). In addition, the suggestion from the SO about the possibility of gluing different elements together paves the way for a hypothetical process in which angular shapes and flat panels are glued together to form the packaging box.

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Appendix A. Classical SO Obtained for the 'Weed' Example

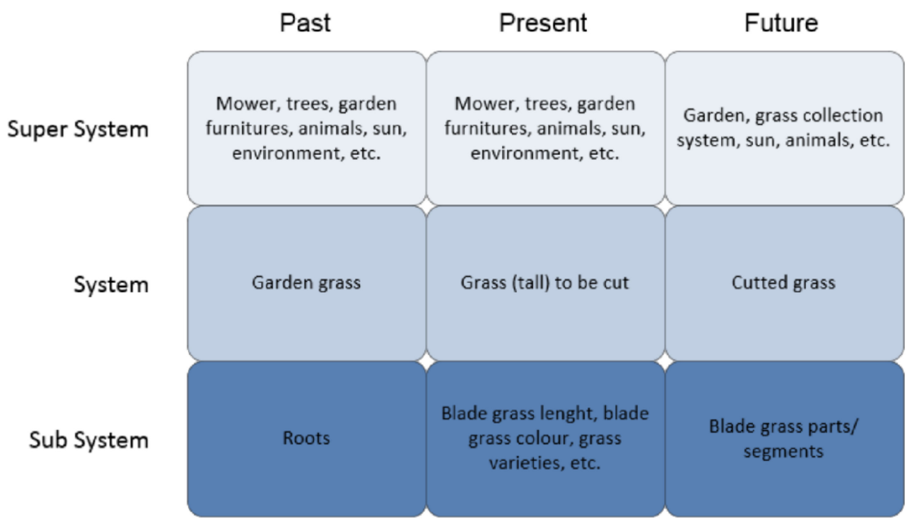

Figure A1. Classical SO for the example considered in Section 2.1.1.

Appendix B. Example for the Proposed SO Approach

The process starts with the definition of the central box of the SO, i.e., by the identification of the system (the grass to be cut) and the problem formulated in form of the question 'What can the system accomplish to mow the grass?' There is no rule for selecting the starting level of detail, which the user identifies by considering the specific task and the available resources. In this example, the system level is considered as the same grass to be cut.

Therefore, since the system level is constituted by the grass, the supersystem can be obtained by considering the plants in the garden, the mower, the sun, etc. Then, the question in the supersystem–present is 'What can an element of the supersystem accomplish to mow the grass?' Differently, the subsystem level could be constituted by the length of the grass strand, the color, etc. Therefore, the problem in the subsystem can be formulated as 'What can an element of the subsystem accomplish to mow the grass?' At this point, the central column of the SO is completed (see Figure A1).

At this point, it is possible to work on the column of the past by searching for the causes that led to the problem. In this specific example, the user can ask him/her self 'Why do we need to cut the grass?', and the answer is quite simple: 'because it has grown too much'. Hence, it is the condition of the length of the grass strands that leads to the need for cutting. Therefore, the problem in the central box of the past column concerns how to avoid or limit the growth of the grass: 'What can the system accomplish to avoid the grass to grow up?' In this column, it is still possible to consider the grass as the 'system', but in a state before the present condition, i.e., when the grass is still short. Then, for the super and subsystem boxes, it is possible to proceeds as for the present column.

For the column of the future, the approach is quite different. Indeed, the user should ask him/herself 'What happens if the grass is not cut?' Different scenarios could be identified, which could lead to multiple parallel planes of the SO. Indeed, if not cut, the grass could support the infestation of small insects, simple aesthetic issues, etc. For this example, only one scenario is considered, i.e., the risk of fall for a small child.

Therefore, the system is identified by the 'uncut grass', and the problem to be formulated at the system level is 'What can the system accomplish to prevent stumbling on the uncut grass?'

Once the system level is defined in the column of the future, the super- and subsystem levels can be obtained by following the same process used for the present and the past columns.

As stated in Section 3, it is possible to obtain additional columns for both the past and the future. However, this example stops at a 3 × 3 matrix.

The rationale followed to fill the column of the future can be used to check the correctness of the column of the past. Indeed, the same rationale characterising the passage from the past to the present should be the same as that of characterising the passage from the present to the future. In the past column, the problem concerns how to avoid the growth of the grass. If this problem is not solved, there is the need to cut the grass (present). Then, if the grass cannot be cut, the problem formulated in the future column appears.

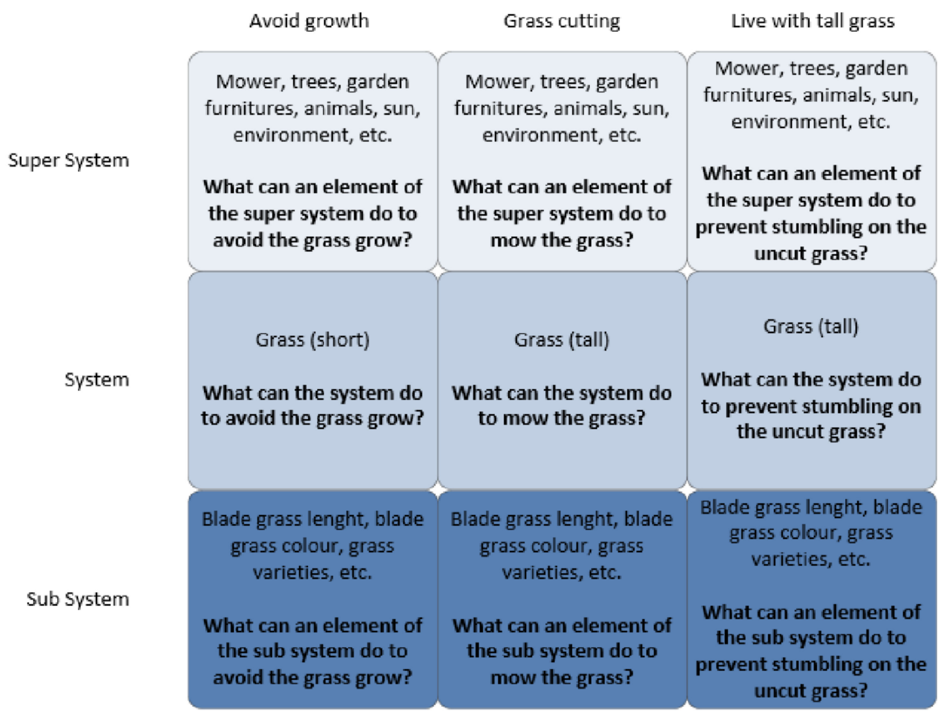

Figure A2. SO obtained with the proposed approach, for the example considered in Section 2.1.1.

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