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An ideality-based map to describe sustainable design initiatives

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Abstract. The terms that constitute Ideality in TRIZ are extremely appropriate to characterize the conflicting prerogatives of value/functionality, and environmental sustainability and human wellbeing. In a system perspective, the latter are mostly ascribable to harmful functions and consumption of resources. The paper introduces a classification of sustainable design initiatives based on the variations of the factors that contribute to Ideality. The classification urges designers to think of possible win-win solutions in which functionalities are not jeopardized by the search for more environmental-friendly solutions. Combining ideality and sustainability is a trigger towards making sustainable solutions more accepted, and, consequently, more effective in preserving the environment. In particular, the individuation of classes of sustainable design endeavors lay bare that the potential reduction of harmful effects is not a sufficient precondition to create sustainable products. Overall, TRIZ, along with its underlying theory and constructs, has proven to provide an effective key of reading for approaching the eco-design field in terms of the extent to which new products and solutions are promising.

Keywords: Ideality, TRIZ, eco-design, super-sustainability, value

1 Introduction

The contradiction between the satisfaction of people's needs and the exploitation of the planet's resources clearly emerges as a challenge for undertaking the sustainable development [1]. On the same line, the goal of increasing the products' eco-efficiency has been summarized as the ability to create more value with less impact by [2]. In this respect, several tools are available to support eco-design in the TRIZ knowledge [3]. Indeed, many scholars highlighted the remarkable contribution of TRIZ in the eco-ideation, e.g. [4-8], and the noteworthy potentiality of TRIZ in the eco-evaluation has been pointed out by [9, 10]. TRIZ usually fulfils eco-design goals since its application tends to boost the value creation by improving systems' useful function (UF), reducing harmful effects (HF) and/or smartly exploiting resources (RES) [11-13]. A systematic TRIZ-based classification of the functional features (i.e. UF, HF, and RES) has been proposed in [14]. In this work, the scholars have distinguished the people's perceived value among design actions aimed to

- Create new UFs or raise the performance of the expected UFs in terms of the threshold achievement, versatility and adaptability under changing conditions, robustness and repeatability of the outputs, and controllability.
- Attenuate or avoid the inconvenience due to HFs exerting on the system, on the super system, or on the object of the main UF.
- Reduce or eliminate the consumption of RES in terms of materials, energy, time, space, information, and direct costs.

The above-mentioned TRIZ-based classification of the functional features comprehensively organizes the creation of value through design actions. Moreover, according to [15], these functional features are included within the concept of Ideality as shown in Equation 1.

$$Ideality = \frac{\sum_i UF_i}{\sum_j RES_j + \sum_k HF_k} \quad (1)$$

Ideality is a cornerstone for the Ideal Final Results (IFR) and for the fourth law of evolution of the technical system, i.e. all systems evolve towards the increase of degree of Ideality [16, 17]. In line with classical TRIZ, the IFR is a system that performs its function without requiring any resources and without causing any harmful effects [15, 17, 18]. Therefore, defining Ideality as in Equation 1, the IFR has an infinite Ideality due to its null denominator [15]. Consequently, it is possible to infer that maximizing Ideality and improving eco-efficiency are two coinciding objectives for a sustainable development.

However, different ways can be followed to increase the Ideality of systems. On the one hand, the maturity of the system affects the most appropriate actions to increase ideality [19]. For instance, technical systems in the early phase of development would tend to increase UF even though this may result in a slight increase in HF and/or RES consumption while more mature technical systems would be more prone to prioritize reducing RES consumption and zeroing out HF even though this may result in a slight reduction in UF [18]. On the other hand, independently from the maturity of the technical system, any design action that leads to change its Ideality results in different perceptions of value and sustainability [20]. To make order in the field and systematize the contribution of eco-design endeavors to Ideality, the goal of the present paper is to create a map that associates changes in Ideality and sustainability results.

2 Rationale behind the work and background information

Through Equation 1, the technical system is described based on i UF, j RES, and k HF. However, the concept behind this equation is purely theoretical. Indeed, the members of this equation have different units of measure and their sum or division has no mathematical and/or physical meaning. Specific accommodation coefficients could be introduced to consider the different quality of the functions and/or different units of measure but to date there is no standard method for evaluating these coefficients.

On the other hand, this expression takes on meaning when comparing two technical systems, i.e. a benchmark (B) and a new design (ND). Indeed, the comparison between these two technical systems allows understanding if (and why) the Ideality of the ND has increased (or decreased) with respect to the Ideality of the B. This variation of Ideality between two technical systems can be expressed as in Equation 2.

$$\Delta Ideality = \frac{\sum_i \Delta UF_i}{\sum_j \Delta RES_j + \sum_k \Delta HF_k} = \frac{\sum_i [UF_i|_{ND} - UF_i|_B]}{\sum_j [RES_j|_{ND} - RES_j|_B] + \sum_k [HF_k|_{ND} - HF_k|_B]} \quad (2)$$

Where the symbol $|_{ND}$ refers to UF, RES, and HF related to the ND and the same applies to the symbol $|_B$ for B. All the members and variables reporting the symbol Δ are clearly meant as differences between ND and B. It is worth noting that, for the scopes of the present paper, the focus is on overall differences for each functional feature (i.e. UF, RES, and HF). Otherwise said, an improvement in terms of UF can be due, for instance, to the enhancement of a specific UF-related performance, as well as an enhancement of a UF1 which outweighs the worsening of a UF2.

If the two technical systems have a different number of UF, RES, and/or HF, the value of i , j , and k are the maximum between the two technical systems. By defining ϕ as one of the functional features, it is possible to summarize any differences that could emerge between the two systems evaluated, as shown in Table 1. In the table, each possible situation is described with a design action and a symbol. The action refers to the Eliminate-Raise-Reduce-Create (ERRC) framework [21], which is able to describe design initiatives that can be performed on a functional feature beyond its stabilization [22]. Actually, the Eliminate and Create actions can be seen in concrete terms as fundamental drops or increases of performances, which can be observed in the trajectories of the factors concurring to Ideality in line with [18]. For sake of clarity, in Table 1, a symbol is reported that intuitively indicates if the numerator and/or denominator (substantially) increases or decreases; obviously, the dash stands for stabilization.

Table 1. Differences in terms of functional units according to the ERRC framework.

If	Than	Action	Symbol
$\phi_{ND} > 0$ & $\phi_B = 0$ (or $\phi_{ND} \gg \phi_B$)	$\phi_{ND} - \phi_B > 0$	CREATE	$\uparrow\uparrow$
$\phi_{ND} > \phi_B > 0$	$\phi_{ND} - \phi_B > 0$	RAISE	\uparrow
$\phi_{ND} = \phi_B > 0$	$\phi_{ND} - \phi_B = 0$	STABILIZE	-
$\phi_B > \phi_{ND} > 0$	$\phi_{ND} - \phi_B < 0$	REDUCE	\downarrow
$\phi_{ND} = 0$ & $\phi_B > 0$ (or $\phi_{ND} \ll \phi_B$)	$\phi_{ND} - \phi_B < 0$	ELIMINATE	$\downarrow\downarrow$

An increased Ideality corresponds to improved resource utilization (and/or Harmful effects reduction) per useful functional unit. Moreover, also a different change in the numerator and in the denominator that leads to a null $\Delta Ideality$ could result into an improved sustainability if an observer, e.g. a consumer, perceives more valuable the design effort in reducing HF/RES with respect to increasing the performance of UF. In

the following sections, different nuances in terms of sustainability achieved by different modalities of increased Ideality are presented and discussed.

3 Proposed relation between sustainable design and Ideality

To develop a ND that has a higher Ideality than the B, different ways can be pursued. On the one hand, design efforts can be focused on to create a new UF or raise the level of performances of existing UF to increase the numerator of $\Delta Ideality$. On the other hand, the goal of the new design could be the reduction of the denominator of $\Delta Ideality$. This can be achieved through the reduction/elimination of HF and/or the reduction/elimination of consumption of RES. These actions are more typically found in eco-design guidelines and principles for sustainable development, e.g. reducing emissions, amounts of consumed materials, undesired impacts on people's dignity and well-being. However, we can underline how the improvement of useful functions can be seen as a trigger to sustainability, like it happens when systems are integrated, e.g. telephone and camera, and the same amount of material serves the satisfaction of multiple human wants.

The 5 actions listed in Table 2 can be applied to the 3 different functional features. Therefore, it is possible to identify $5^3 - 1 = 124$ different ways to change the level of ideality (one is related to no changes in terms of Ideality). However, only 53 combinations lead to an increase in Ideality, 18 combinations lead to an unstable variation (i.e. the numerator and the dominator varying of the same amount in different directions). As it is mentioned before, one combination leads to unaltered Ideality and the other 53 lead to a decrease in terms of Ideality. These combinations, which are summarized in Table 2, can be (logically, in authors' view) classified according to sustainability initiatives following the rules described in the bullet list below.

- Any combination that leads to a lower $\Delta Ideality$ or an unstable $\Delta Ideality$ that involves an overall increase in the denominator can be defined as a Not Sustainable (NS) combination.
- Any combination that leads to an increase in the numerator and a simultaneous decrease in the denominator can be considered a "Super" combination.
- Any combination that leads to a decrease of the denominator due solely by the reduction of RES can be considered a "Resource Oriented" combination.
- Any combination that leads to a decrease of the denominator due solely by the reduction of HF can be considered a "Harmfulness Oriented" combination.
- Any combination that leads to an increase in HF and, contextually, a decrease in RES or vice versa can be considered a Contradiction, because of the presence of a conflicting move.
- Any combination that leads to a constant UF and, at the same time, to a reduction of the denominator can be considered Traditional in terms of sustainability and eco-design.

- Any combination that leads to increased Ideality and a decreased UF can be related to the Green Consumer because the consumer could perceive more value in the reduction of the denominator rather than being unsatisfied with the reduction of the numerator.
- Any combination that leads to increase UF without any reduction of the denominator can be related to the Quality. This is because, with the same quantity at the denominator (RES and HF), the solution provides better and/or higher UF; this is therefore related to the perception of its quality.
- Any combination that leads to a constant Ideality by keeping the UF constant and varying the RES and HF of the same amount in opposite directions can be considered Contradictory and Uncertain. Indeed, it is not possible to know a priori if this solution is more sustainable because the Ideality is almost constant and, at the same time, there is an unbalance between RES and HF.
- Any combination that leads to an almost constant Ideality by decreasing both the numerator and the denominator can be considered as a Sacrifice. This is similar to Green Consumer but, in this case, the Ideality is almost constant.

Table 2. Combinations of Δ Ideality (I-Increase; D-decrease; ?-unstable ; S-steady).

$\sum_k \Delta HF_k$	$\sum_j \Delta RES_j$	$\sum_i \Delta UF_i$				
		↓↓	↓	-	↑	↑↑
↓↓	↓↓	I	I	I	I	I
↓	↓↓	I	I	I	I	I
↓↓	↓	I	I	I	I	I
↓	↓	?	I	I	I	I
-	↓↓	?	I	I	I	I
-	↓	D	?	I	I	I
↓↓	-	?	I	I	I	I
↓	-	D	?	I	I	I
↑	↓↓	D	?	I	I	I
↓↓	↑	D	?	I	I	I
-	-	D	D	S	I	I
↑	↓	D	D	?	I	I
↓	↑	D	D	?	I	I
↑↑	↓↓	D	D	?	I	I
↓↓	↑↑	D	D	?	I	I
↓	↑↑	D	D	D	?	I
↑↑	↓	D	D	D	?	I
↑	-	D	D	D	?	I
-	↑	D	D	D	?	I
↑	↑	D	D	D	D	?
↑↑	-	D	D	D	D	?
-	↑↑	D	D	D	D	?

↑↑	↑	D	D	D	D	D
↑	↑↑	D	D	D	D	D
↑↑	↑↑	D	D	D	D	D

A more detailed classification can be found in Table 3. In this table, the increase and unstable combinations described in Table 2 are analyzed more in details. The numbers found in Table 3 match the definitions of kinds of sustainability in the bullet list following the table. Still in the table, NS stands for Not Sustainable i.e. the ideality tends to decrease or to remain constant with an unjustified increase in the denominator. ND=B means that the New design and the Benchmark match in terms of ideality and its impacting factors.

Table 3. Relation between different combination of Δ Ideality and sustainability initiatives.

$\sum_k \Delta HF_k$	$\sum_j \Delta RES_j$	$\sum_i \Delta UF_i$				
		↓↓	↓	-	↑	↑↑
↓↓	↓↓	9	9	5	1	1
↓	↓↓	9	9	5	1	1
↓↓	↓	9	9	5	1	1
↓	↓	16	9	5	1	1
-	↓↓	17	10	6	2	2
-	↓	NS	17	6	2	2
↓↓	-	18	11	7	3	3
↓	-	NS	18	7	3	3
↑	↓↓	NS	19	8	4	4
↓↓	↑	NS	19	8	4	4
-	-	NS	NS	ND=B	12	12
↑	↓	NS	NS	15	13	13
↓	↑	NS	NS	15	13	13
↑↑	↓↓	NS	NS	15	13	13
↓↓	↑↑	NS	NS	15	13	13
↓	↑↑	NS	NS	NS	NS	14
↑↑	↓	NS	NS	NS	NS	14
↑	-	NS	NS	NS	NS	14
-	↑	NS	NS	NS	NS	14
↑	↑	NS	NS	NS	NS	NS
↑↑	-	NS	NS	NS	NS	NS
-	↑↑	NS	NS	NS	NS	NS
↑↑	↑	NS	NS	NS	NS	NS
↑	↑↑	NS	NS	NS	NS	NS
↑↑	↑↑	NS	NS	NS	NS	NS

1. Super Sustainability, featured by an increase in UF and a decrease in both RES and HF. This kind of sustainability is the biggest challenge in design and the one that comes closest to the Ideal Final Result (IFR).
2. Sustainability Resource Oriented, characterized by an increase in UF and a decrease in RES (keeping HF constant). This kind of sustainability is an excellent outcome, especially for Bs that have a high impact in terms of RES and a low impact in terms of HF.
3. Sustainability Harmfulness Oriented, in case of an increase in UF and a decrease in HF (keeping RES constant). This kind of sustainability is an excellent outcome, especially for Bs that have a high impact in terms of HF and a low impact in terms of RES.
4. Sustainability with Contradiction, i.e. those circumstances in which there is an increase of UF and, contextually, an overall decrease of the denominator but with an opposite direction between HF and RES. This kind of sustainability is a good result since it allows increasing the UF and, at the same time, decreasing the denominator, even if there is an imbalance between RES and HF that should be evaluated in the specific application (and likely addressed with TRIZ tools because of the presence of impactful contradictions).
5. Traditional Sustainability, i.e. when both the RES and HF decrease, and the UF is unaltered.
6. Resource-Oriented Traditional Sustainability, i.e. when the technical system maintains the same performance in terms of UF and HF, while the RES decrease.
7. Harmfulness-Oriented Traditional Sustainability, i.e. when the technical system keeps the same performance in terms of UF and RES, whilst the HF are reduced.
8. Traditional Sustainability with Contradiction, i.e. when the UF is unchanged, and there is an overall decrease of the denominator but with an opposite direction between HF and RES.
9. Sustainability for the Green Consumer, which takes place when the overall Ideality increases because the denominator decreases more than the numerator does. This is due by the fact that UF performance decreases and, at the same time, RES and HF decreases more substantially.
10. Resource-Oriented Sustainability for the Green Consumer, i.e. when the overall Ideality increases because the RES decreases more than the UF does (keeping HF constant).
11. Harmfulness-Oriented Sustainability for the Green Consumer, i.e. when the overall Ideality increases because the HF decreases more than the UF does (keeping RES constant).
12. Sustainability as Quality, i.e. when the increase in sustainability is not due to a decrease in the denominator (which remains constant) but to an increase in UF.

13. Sustainability as Quality with Contradiction, i.e. when the UF increases and, at the same time, the denominator presents an opposite direction between HF and RES that leads to no variations of the denominator value.
14. Counter-intuitive Sustainability as Quality, i.e. when the overall increase in the denominator is justified by the greater increase in UF.
15. Contradictory and Uncertain Sustainability, i.e. when Ideality tends to remain constant (as well as the UF does) but there is an imbalance in the terms of the denominator. In this case, further analysis has to be performed to investigate whether the ND is more sustainable than B. Indeed, it is possible that the different distribution of the denominator terms leads to more sustainable solutions, but also the opposite might apply.
16. Sustainability as a Sacrifice, i.e. when, in order to achieve a decrease in RES and HF, UF decreases to “a proportional extent”.
17. Sustainability as a Resource-Oriented Sacrifice, i.e. when, in order to achieve a decrease in RES, UF decreases to “a proportional extent” (keeping HF constant).
18. Sustainability as a Harmfulness-Oriented Sacrifice, i.e. when, in order to achieve a decrease in HF, UF decreases to “a proportional extent” (keeping RES constant).
19. Sustainability as a Sacrifice with a Contradiction, i.e. when Ideality is overall kept constant with a decrease in UF and a decrease of the denominator due with different changes as of RES and HF.

4 Discussion

The speculation of this paper starts from considering the evolution of technical systems, and, specifically, the fact that the variables affecting Ideality (UF, HF, and RES) can be stabilized, increased (incrementally or radically), or decreased (incrementally or radically). These variations are mirrored by models diffused in design and business domains, where those are used to compare different systems based on the quality and performances of different product attributes, see [23] for a recent example. It follows that the redefinition of product profiles in terms of their characteristics, attributes and fulfilled (customer) requirements has an effect on the Ideality of systems, based on the changes that UF, HF and RES undergo. In the authors' view, these changes have also a direct and predictable effect on sustainability. The fact that the evolution of systems leads to increase their Ideality, which is mirrored by an overall better sustainability is not new in the TRIZ domain, e.g. [6], but the mainstream approach is to adapt TRIZ tools and concepts, including Ideality, to the scopes of sustainable or eco-design, e.g. [24] among recent contributions. By combining the possible variations of the Ideality terms, not only the authors show how the growth of Ideality is conceptually mirrored by positive effects on sustainability (apart from a few arguable circumstances), but also do they stress that different sustainable design endeavors can be recognized. Those endeavors are distinguished into classes featured by different kinds of and intensities contributions to sustainability, as well as by different effects on people's possible value

perception. Still in line with the authors' research efforts [20], light has been shed on the insufficiency of eco-design principles to develop attractive products, which can result poorly sustainable in the long term.

Indeed, some sustainable initiatives are deemed as appreciable just for green consumers and for those available to sacrifice functionality with the willingness to safeguard the environmental and social dimensions of sustainability. Still, inconsistent and conflicting moves can emerge despite them being coherent with an overall growth of Ideality, hence they do not result in the violation of TRIZ laws.

Despite their current abstract form, the classes are not be seen as a mere conceptualization of the relation between Ideality and sustainability. They can be viewed as a trigger to pose new objectives, to carefully consider residual contradictions, and, ultimately, to target the so named "Super Sustainability". The latter is thought as a win-win situation where the Ideality terms are harmonically modified in the desired way (UF increases, RES and HF decrease). Possible examples of this kind can represent as a further source of inspiration for designers. However, if one considers the typical evolution of Ideality as an S-shaped curve [18], it can be said that moves consistent with Super Sustainability are supposedly infrequent. Nevertheless, Super Sustainability can be also considered as a long-term objective, to be likely addressed by a reasoned combination of other kinds of sustainability moves.

5 Implications, limitations and final remarks

Beyond the fact that the present paper is plainly a preliminary approach to addressing the important relation between Ideality and sustainability in a systematic way, other limitations can be claimed. The classification has been developed qualitatively, based on a presumably logical approach, which some readers can disagree on, and is not mature enough to assess the Ideality of new eco-designed product. Likewise, comparisons between multiple eco-designed alternatives can be made in some circumstances only. In addition, as already stressed in Section 2, the variations of functional features can be caused by different combinations of changes, whose effects on ideality and sustainability could be studied at a higher level of granularity. Moreover, some variations could lay bare the presence of contradictions within functional features (diffused according to [25]) to be solved with classical TRIZ tools.

Despite these limitations, the main implications and usefulness of the paper can be summarized as follows. The mapping of eco-design initiatives pushes design teams to consider a system-level thinking when it comes to functionalities and environmental friendliness. The categories and typologies of eco-design endeavors might result as a specification of firms' approach towards sustainability, mission, characterizing aspects and target customers.

From a scientific point of view and in the relation to the interests of the TRIZ community, the authors claim some fundamental original aspects of this research. While approaching eco-design with the concept of Ideality is not new, the way this is has been

done here is unprecedented. Similarly, the definition of classes of eco-designed products has not been made explicit so far, while it is straightforward that some initiatives are successful, while others are not.

Eventually, the considerations above support that the need to address Ideality as a whole in eco-design is a first indication for design teams. Other players can benefit from the map in terms of understanding and/or assessing the compliance of eco-designs in terms of them targeting the most favorable conditions to be attractive in the market.

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