Model for Redesigning User-Centric Sustainable Products

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Abstract

This article introduces a comprehensive model that integrates TRIZ (Theory of Inventive Problem Solving) and Design Thinking to design or redesign user-centered sustainable products. The proposed methodology aims to support small and medium-sized enterprises (SMEs) by offering an accessible and practical approach that balances technical and commercial feasibility while addressing consumer needs. The model underwent implementation in the conceptual redesign of a bento-style lunch box, yielding significant improvements over the original design—particularly in volume reduction, ease of transport, and lower environmental impact. The fusion of the technical (TRIZ) and social (Design Thinking) approaches proved effective, enabling the resolution of specific technical challenges while simultaneously aligning the solution with user expectations and requirements. This model holds substantial potential to streamline the development of new products or enhance existing ones within SMEs. Future research may validate the model across various industrial contexts and assess its long-term economic and environmental impact.

Keywords
Product design, Sustainable development, Small and medium-sized enterprises, Technological innovation, TRIZ (Theory of Inventive Problem Solving), Design thinking

Introduction

Single-use packaging, primarily employed in sectors such as food, logistics, and retail, ranks among the leading sources of solid waste (Geyer et al., 2017). Its immediate consumption followed by near-instant disposal defines a short life cycle, which not only exacerbates waste accumulation in terrestrial and marine ecosystems but also intensifies major global challenges such as climate change and biodiversity loss (Programa de las Naciones Unidas para el Medio Ambiente - United Nations Environment Programme, 2023).

Various studies have explored strategies to reduce the environmental impact of product design (Trujillo-Suárez MAIA et al., 2016), including circular economy-based models (Ellen MacArthur Foundation, 2024) and ecodesign approaches aimed at improving product life cycle efficiency (Chen, 2020). Among these, the triple bottom line model evaluates product design from three interrelated dimensions: economic, environmental, and social (Muñoz, 2024). However, despite their relevance, these strategies often encounter adoption barriers within small and medium-sized enterprises (SMEs) due to financial, technological, and operational limitations (Kirchherr et al., 2018; Geissdoerfer et al., 2023).

Redesigning sustainable products based on user needs has gained increasing relevance (Bovea et al., 2018; Geissdoerfer et al., 2023). This growing interest has led to the development of a wide range of methodological approaches, shaped by the tension between utility-driven design and the lack of contextual consideration in product use. As a result, researchers and practitioners have sought methodologies that integrate sustainability, functionality, and innovation, particularly in resource-constrained environments.

The model proposed in this article builds upon prior research in which an early version of the methodology guided the redesign of a coffee mug (Paredes Páramo et al., 2022). The results confirmed its technical feasibility and user-centered effectiveness, while also revealing the need for a more structured and adaptable framework. In response, the authors developed an integrated proposal that merges Design Thinking and TRIZ tools within a unified methodological structure.

Given that one of the primary obstacles for SMEs lies in the lack of resources to develop physical prototypes in early design stages, the present study adopts virtual prototyping as a means of representing and evaluating the proposal (Christiansen et al., 2022; de Sá & Rix, 2000). This approach has proven effective in anticipating functional, technical, and perceptual attributes without the need to manufacture a physical object, as evidenced by recent studies (Wang & Liu, 2023; Chu & Kao, 2020). These findings support the methodological relevance of virtual prototyping in innovation processes with limited resources.

Within this context, the study raises the following research question: How can SMEs efficiently and affordably design sustainable products while addressing their operational and resource constraints? The authors hypothesize that integrating TRIZ and Design Thinking provides a structured and replicable framework that balances the technical and social dimensions of design, while fostering innovative solutions without compromising economic and commercial viability (Deiner, n.d.).

Literature Review

One of the most influential methodological frameworks in the field of innovative and sustainable design originates from the Theory of Inventive Problem Solving (TRIZ), developed by Russian engineer Genrich Altshuller. This approach offers a robust framework for generating solutions that balance innovation and sustainability (de Jesus Pacheco et al., 2019; Ilevbare et al., 2013). Applications across various industries have confirmed TRIZ's adaptability to diverse environmental challenges (C. K. M. Lee et al., 2024). Nonetheless, its highly technical and rigid structure often proves unsuitable for small and medium-sized enterprises (SMEs), particularly those with limited or no formal engineering background. This gap highlights the pressing need for more accessible and user-friendly methodologies.

Concurrently, Design Thinking has emerged as a user-centered alternative. This methodology has gained considerable traction in recent years due to its emphasis on user needs and perceptions, along with its capacity to rapidly generate multiple innovative solutions (Brown, 2009). By grounding the process in user empathy, Design Thinking enables real consumer needs to occupy a central role, thereby enhancing product acceptance and perceived value (Solfa et al., 2018). However, despite its strengths, this approach lacks a structured technical component capable of addressing complex engineering problems.

In response to the individual limitations of these frameworks, scholars have proposed an integrated methodological strategy that combines TRIZ and Design Thinking (Li et al., 2024). Case studies ranging from innovation in Colombian coconut-producing communities (Delgado Eraso et al., 2023) to the redesign of packaging for older adults (Jeong et al., 2021) have

demonstrated that this integration fosters the development of sustainable and innovative solutions while mitigating the limitations inherent to each method.

Justification of the Proposed Model

As outlined in the literature review, each methodological approach contributes valuable elements to sustainable design, yet significant gaps emerge when applied in isolation. For instance, technical methodologies such as TRIZ or value analysis effectively address engineering conflicts through structured logic, yet they often demand specialized expertise and insufficiently incorporate end-user perspectives (Ilevbare et al., 2013; Lin & Chen, 2021). In contrast, human-centered approaches such as Design Thinking, Service Design, or Human-Centered Design foster empathy and collaborative creativity (Mohamad et al., 2025), although they lack systematic tools to resolve technical or structural constraints inherent in design challenges. Lastly, environmental assessment frameworks like Life Cycle Analysis (LCA) offer detailed evaluations of product impact but remain underutilized in SMEs due to their reliance on specialized software, complex databases, and trained personnel (Ecochain, 2024).

In response to this disciplinary fragmentation, the model proposed in this study synthesizes the strengths of each approach. It applies TRIZ's logical structure to identify and resolve technical contradictions, while simultaneously integrating Design Thinking's empathetic flexibility to ensure that resulting solutions address real user needs. Unlike models that concentrate solely on one design dimension, this proposal introduces a hybrid, iterative, and practical alternative tailored for real-world application—without requiring advanced training, expensive software, or large multidisciplinary teams.

Metodology

This study employed a qualitative exploratory approach to assess the applicability of a model integrating TRIZ and Design Thinking methodologies in the redesign of user-centered sustainable products. The qualitative approach enabled an in-depth examination of user perceptions and expectations, while also facilitating the identification of technical challenges that could be addressed through a structured and replicable methodological framework.

The research process involved applying the model to the conceptual redesign of a bento-style lunch box (Figure 1), selected for its widespread availability, frequent use among students, and considerable potential for improvement in terms of functionality, portability, and environmental sustainability.

Figure 1. Bento-style lunch kit box

Source: Own elaboration using ChatGPT.

During data collection, the research adopted a case study design (Canta-Honores, 2021). A mixed questionnaire—comprising both open- and closed-ended questions—was distributed electronically to 81 students at the Universidad Politécnica Metropolitana de Hidalgo (UPMH). The sample was selected through non-probability convenience sampling, focusing on students enrolled in courses related to design, sustainability, or product innovation. The questionnaire explored variables such as usage habits, material preferences, and key decision-making factors when purchasing this type of product.

Data analysis followed the thematic analysis technique (Braun & Clarke, 2006), encompassing the stages of initial coding, theme development, review, and interpretation. This method enabled the identification of recurring patterns and divergences in participant responses, which were systematically organized to inform the iterative stages of the proposed model. Additionally, source triangulation (de Sevilla España Aguilar Gavira & Osuna, n.d.) was conducted by comparing the questionnaire results with previously reported findings from online sources. This strategy supported the contextual relevance of the model based on real-world user scenarios.

Although the questionnaire included closed-ended items to identify specific preferences (e.g., materials, usage behaviors, storage habits), it also incorporated open-ended questions that allowed participants to describe personal experiences, frustrations, and suggestions for improvement. These qualitative insights enriched the thematic analysis by revealing issues such as the perceived fragility of current products and the inconvenience of transporting multiple components separately.

As with any qualitative study based on non-probabilistic sampling, the findings cannot be generalized to the entire student population. Nevertheless, the results offer a solid foundation for developing and refining the model, as they derive from real-world data and a systematic thematic framework. Furthermore, the methodology builds upon a prior redesign experience involving the development of a reusable cup prototype (Paredes Páramo et al., 2022). That earlier project contributed to refining the model's structure prior to the current application. While the present validation remains conceptual rather than empirical, it represents a necessary step before future research involving physical fabrication and performance testing in actual contexts.

Regarding ethical considerations, informed consent was obtained from all participants. Personal data protection and response anonymity were ensured in accordance with ethical principles applicable to non-clinical academic research (Association, 2013).

Description of the Proposed Integrated Model

The proposed model combines two complementary methodological approaches—TRIZ and Design Thinking—within a sequential and iterative framework aimed at product redesign from both technical and social perspectives. This integration seeks to resolve technical contradictions without losing sight of real user needs, making it especially valuable in resource-constrained environments such as those commonly faced by small and medium-sized enterprises (SMEs).

The model consists of five iterative stages, each incorporating tools from the foundational methodologies. Design Thinking contributes an inductive, empathy-driven approach that enables the identification of latent needs and the reframing of problems from the user's point of view (Altman et al., 2019). In contrast, TRIZ introduces a deductive logic focused on systematically resolving technical contradictions through proven inventive principles (Kretzschmar & Chekurov, n.d.). This combination allows for comprehensive analysis, conceptualization, and redesign of products, services, or processes, while maintaining a balance among technical feasibility, sustainability, and user impact. The following outlines the model's core stages:

1. Empathize: In-Depth Understanding of the User
This initial phase focuses on identifying the problem from the user's experience. It involves qualitative, human-centered tools designed to uncover unspoken needs, frustrations, and expectations (Hartung & Rottenberg, 2019).

Key tools include:

- Semi-structured interviews
- Contextual observation of product use
- Empathy mapping
- Customer journey analysis

The data collected supports the identification of behavioral patterns, evaluation of the actual functionality of current solutions, and the discovery of improvement opportunities. This stage prioritizes the user's perspective over technical assumptions.

2. Technical Problem Definition
Building on the findings from the empathy phase, TRIZ tools convert qualitative insights into specific technical contradictions.

Key activities (TRIZ | Tool Tec, n.d.):

- Identification of technical contradictions (e.g., increasing strength without adding weight)
- Selection of relevant technical parameters (from TRIZ's 39 standard parameters)
- Application of the contradiction matrix
- Selection of recommended inventive principles

This stage transforms both direct and indirect user needs into structured technical challenges, preventing the design from defaulting to intuitive solutions or those constrained by the designer's prior experience.

3. Ideation and Solution Generation
Once the technical conflicts and corresponding inventive principles have been identified, the process transitions into the creation of preliminary design proposals. At this point, Design Thinking re-enters as a filter to prioritize solutions that preserve a user-centered focus.

Suggested activities:

- Structured brainstorming sessions guided by selected inventive principles
- Solution prioritization based on usability, technical feasibility, and sustainability
- Preliminary visual representation (e.g., sketches, wireframes, flowcharts)
- Optional tools: SCAMPER technique, analogical reasoning, or mind mapping—depending on the type of redesign

This stage combines creative exploration with previously identified technical constraints, thus avoiding overly conservative or unrealistic proposals.

4. Conceptual Prototype Development
The most viable ideas converge into a visual or physical representation of the product, without requiring full-scale manufacturing. Selected concepts are expressed through low- or medium-fidelity prototypes, which help visualize and assess general functionality prior to formal validation or implementation.

Prototype types may include:

- Hand-drawn sketches
- 3D digital models (e.g., CAD, Blender, SketchUp)
- Functional diagrams or process flow maps (for services or systems)
- Physical representations using recycled materials or prefabricated modules

The goal of this stage does not lie in finalizing the product's aesthetic features, but rather in confirming that the solution meets the functional, technical, and experiential requirements defined in earlier phases.

5. Iterative Evaluation and Feedback

This final phase assesses whether the proposed solution aligns with user-defined criteria and incorporates feedback mechanisms that may prompt new iterations. It emphasizes critical reflection on prototype outcomes. Although this may involve user testing or simulation, the core priority is to ensure the model remains flexible and responsive to observed shortcomings.

Evaluation options include:

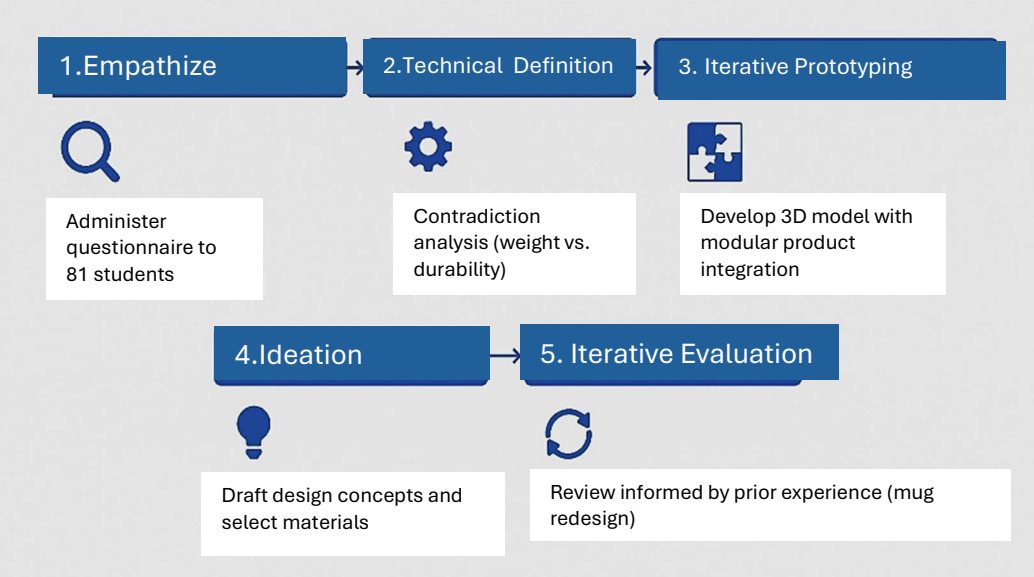
- Pilot testing or interviews with simulated users
- Digital behavior simulation (e.g., flow, spatial use, interaction)
- Feedback from key stakeholders (e.g., clients, technicians, operators)
- Agile iteration cycles (plan, execute, review, adjust)

If the proposed solution fails to meet the initial objectives, this stage enables a return to previous phases for refinement. Such iterative loops prevent the process from settling on suboptimal designs due to insufficient validation.

The proposed model aims to offer a flexible, adaptable methodology suitable for varying degrees of complexity across diverse sectors—particularly within SMEs, which often face significant resource constraints but seek to advance toward more efficient and sustainable design processes (Bocken et al., 2016). Its clear structure allows for application in both academic and business environments, without requiring specialized training in engineering, design, or innovation.

Figure 2 below illustrates the flow of the integrated model as applied to the lunch box redesign. It also outlines the specific tools and elements employed at each stage, enabling a direct comparison between methodological phases and their practical execution.

Figure 2. Integrated model applied to the redesign of a lunch box



Source: Author's own elaboration based on collected data.

Application Example: Lunch Box Redesign as an Illustrative Case Study

As an application example, the conceptual redesign of a reusable lunch box served to demonstrate the applicability and practical value of the proposed model for user-centered sustainable product redesign, through the integration of TRIZ and Design Thinking methodologies. Rather than focusing on evaluating the physical performance of the product under real-use conditions, the study aimed to assess the methodological viability of the model and its ability to generate innovative and coherent solutions from both technical and social perspectives. The goal did not lie in achieving formal product innovation, but in demonstrating the effectiveness of the approach through a familiar use case with significant improvement potential.

Phase 1. Empathize (problem identification from the user's perspective)
The process began with the distribution of semi-structured questionnaires to 81 university students who frequently use this type of product to transport their meals. Based on the collected responses, an empathy map (Table 1) was constructed to identify users' needs, preferences, and emotional responses related to the use of reusable lunch boxes.

Table 1. User Empathy Map

<table>
<tr><td colspan="2">What do they think and feel?
They value durability and sustainability. Concerns arise regarding fragile or unreliable materials.</td></tr>
<tr><td>What do they hear?
They hear recommendations about sustainable products but remain skeptical about their actual functionality.</td><td>What do they see?
They notice that peers frequently use low-quality or poorly functioning containers.</td></tr>
<tr><td colspan="2">What do they say and do?
They express preferences for materials such as bamboo, stainless steel, and bioplastics. They show interest in compact designs. They use containers daily, store cutlery separately, and often misplace components.</td></tr>
<tr><td>Frustrations and needs:
Difficulty storing parts, easily breakable materials, uncomfortable cutlery.</td><td>Needs:
Modular design, ease of storage, portability, durable yet lightweight materials.</td></tr>
</table>

Source: Author's own elaboration based on collected data.

The application of this tool revealed that the most highly valued features included durability, ease of use, and modular design. Common issues identified involved material fragility and difficulties with storage. Preferred materials among users were bamboo, bioplastics, and stainless steel. Modular configurations emerged as the most favored due to their enhanced functionality.

Phase 2. Technical Problem Definition (Application of TRIZ Elements)
Following the analysis of the results from Phase 1, the Altshuller contradiction matrix was applied (K. Lee, 2018), yielding the following contradictions and parameters:

- Contradiction 1: The material must be strong yet lightweight.
- Contradiction 2: The container must offer ample storage capacity without compromising portability.
- Contradiction 3: Cutlery should remain compact while retaining functionality and ergonomic comfort.

Based on these contradictions, the following inventive principles were selected (Innovation Algorithm TRIZ Systematic Innovation and Technical Creativity PDF | PDF, n.d.):

- No. 8 – Counterweight

- No. 35 – Parameter changes

These principles informed the design of a product adaptable to everyday usage conditions, maintaining a balance between functional efficiency and reduced environmental impact.

Phase 3. Product Design (Ideation)
During this stage, preliminary sketches and conceptual models were developed. The new design (Figure 3) incorporates sustainable materials:

PLA bioplastic (polylactic acid) was selected for the main container due to its biodegradability, favorable thermal properties, and resistance to deformation (Linssen, 2024).

Bamboo was chosen for the cutlery thanks to its light weight, antibacterial properties, and low environmental impact (Ren, 2023).

Food-grade silicone was used for the collapsible cup, offering flexibility, thermal resistance, and ease of storage in compact spaces (Frank, 2022).

Figure 3. Sketches of the container, cutlery, and collapsible silicone cup

Source: Author's own elaboration using ChatGPT.

In order to provide a comparative illustration of the improvements achieved through the redesign model, Table 2 outlines the key differences between the traditional lunch box design and the proposed version.

Table 2. Comparison Between the Traditional Design and the Proposed Redesign of the Lunch Box

Criterion	Traditional Design	Proposed Redesign
Structure	Separate container, cup, and cutlery	Integrated elements in a single compact system
Materials	Conventional plastic	PLA bioplastic, bamboo, and food-grade silicone
Portability	Low (takes up more space)	High (collapsible cup and compact cutlery)
Environmental Impact	High (non-biodegradable plastics)	Low (biodegradable and reusable materials)
Durability	Medium	High
Modular Design	Absent	Present

Source: Author's own elaboration based on collected data

Phase 4. Conceptual Prototype Development

A three-dimensional virtual prototype was developed (Figure 4) to validate the technical, functional, and usability coherence of the redesigned product. The solution was structured into a compact design, where the cutlery fits into an intermediate tray, the cup folds into itself, and the entire system is enclosed by an outer lid—unlike the original product, where all elements were stored separately.

Figure 4. Traditional Container vs. Redesigned Version Featuring Reduced Volume, Modular Design, and Integrated Cutlery

Source: Author's own elaboration using ChatGPT.

This detailed representation enabled the visualization of sustainable material integration, spatial optimization through modular design, and the efficient arrangement of components, thereby facilitating future material prototyping.

Phase 5. Iterative Evaluation and Feedback

Drawing on the findings from the empathy phase and the technical analysis using TRIZ, an iterative evaluation process allowed for the refinement of proposed solutions. This continuous feedback loop—combined with prior experience applying the method in a functional redesign—reinforces the utility of the proposed integrated approach in addressing real-world challenges within sustainable product development environments.

Results of Applying the Integrated Method to the Lunch Box Redesign

The implementation of the proposed redesign model validated its potential as a comprehensive strategy for developing user-centered sustainable products. Integrating both methodologies into a single framework enabled the resolution of technical contradictions while maintaining a clear focus on the needs and preferences of the end user.

The questionnaires administered to the sample revealed that the most valued attributes among consumers were durability, ease of use, and modular design. These findings align with previous studies (Bocken et al., 2016), which emphasize that sustainable product design largely depends on functional performance and the user's perception of convenience.

From a technical standpoint, the use of the TRIZ contradiction matrix proved essential for identifying key design conflicts. Contradictions such as "lightweight vs. strength" and "capacity vs. portability" served as the foundation for selecting appropriate inventive principles.

A key strength of the proposed model lies in its ability to align technical and social criteria through an iterative perspective, allowing continuous refinement of solutions based on the outcomes observed at each stage. The methodological exercise demonstrated the feasibility of the conceptual design generated through this process.

Ultimately, the model functions as an adaptable tool for a wide range of products, enabling redesign processes to be restructured from the early stages through to prototyping. Its methodological guidance remains replicable and accessible to SMEs, allowing them to innovate their design processes and effectively address systemic problems, while simultaneously enhancing the perceived value of the final product from the user's perspective (Delgado Eraso et al., 2023).

Conclusions and Recommendations (Discussion)

This article presented a product redesign model based on the methodological integration of TRIZ and Design Thinking. The proposed approach proved to be a useful tool for simultaneously addressing technical challenges and user-centered design needs.

The findings demonstrated that combining these methodologies facilitated the systematization of the redesign process by balancing social and technical dimensions. By analyzing user needs, the model enabled the identification of key expectations, which in turn supported the development of viable solutions.

This approach aligns with previous research (Delgado Eraso et al., 2023; K. Lee, 2018), which has also explored the complementarity between TRIZ and user-centered methodologies, emphasizing their positive impact on sustainable product development.

The application of the integrated model in this case reinforces its validation, demonstrating its utility in redesigning user-centered sustainable products. Based on the results, it can be concluded that the integration of TRIZ and Design Thinking effectively addresses both technical and social design challenges, even in resource-constrained contexts such as those commonly encountered by SMEs. The results are consistent with prior methodological experiences (Paredes Páramo et al., 2022), further strengthening the proposed framework.

Future research will focus on evaluating the model in various industrial sectors and with products involving greater technical complexity. Additionally, physical prototyping and functional testing will be undertaken to enhance the model's applicability in real-world settings.

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