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Developing a method to improve unknown identification and design efforts for environmental transition: a case study in the packaging industry

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Abstract

Most manufacturing companies have tested and adopted sustainable design methods to navigate their product's environmental transition. While successful at first in enhancing their environmental performance, these companies later struggle to pursue their environmental transition. This entails mastering two critical competencies: identifying transition unknowns, and fostering adequate design efforts. This action research with an innovative design intermediary - which has completed four sustainable packaging missions - reveals the specific design barriers encountered for environmental transition.

Keywords: design methods, unknown, sustainable design, C-K design theory, packaging

1. Introduction

Donella Meadows emphasizes the requirements of clear models and information before implementation. In her 1993 speech "Down to Earth", she highlights: *"There is a very great tendency to go immediately to implementation and say and talk first and primarily in that arena [...] but before that we need to be sure that our models are clear that our information is accurate and above all we need to be sure that we know where we are going"*. In response to global pressures and increased social awareness, many companies are implementing various practices to enhance the environmental performance of their products. They are revising design processes to minimize environmental impacts, yet often without a precise understanding of the required design efforts. The successful implementation of the appropriate capabilities depends on firms' ability to navigate and uncover the level of unknowns they face. These unknowns correspond to variables without identification, understanding or predictability, which can influence rational choices. Although crucial in the design process, companies overlook assessing some of them for the environmental transition. Taking an example from the emergence of recycling in the 1990s European automotive industry, the evaluation of design efforts proved challenging, such as the establishment of a car waste value chain. Learning to reinforce monitoring and standards setting became fundamental to achieve a recycling network (Aggeri and Hatchuel 1996). And consensus on standards constituted a major unknown for an efficient design process, illustrating a lack of understanding of the nature of unknowns in Sustainable Design. This underscores the need to uncover and define them to apply suitable strategies for Sustainable Product Development. Thus, transition design necessitates assessing unknowns, an aspect not extensively covered in existing literature. To address this gap, we will leverage methods/tools developments for Sustainable Design along with the lens of design theory on managing the unknown. These theoretical perspectives should lay the groundwork for characterizing transition unknowns. To contribute further, we will use action research methodology with an innovative design intermediary, which completed four sustainable design missions for packaging manufacturers. Despite 30 years of Eco-Design practices, the packaging industry remains relevant due to persistent environmental issues. Eurostat's 2023 analysis reveals an 11kg increase in EU citizens' packaging waste generation per inhabitant compared to 2020. Therefore, based on these four missions, we will identify the common challenges to describe potential lock-in situations related to unknowns. Most importantly, we will explore how Innovative Design can uncover new types of transition unknowns.

2. Literature review

2.1. Sustainable design barriers

The analytical approach of 'Sustainable Product Development' (SDP) has evolved over time (McAloone and Pigosso 2017), transitioning from a product focus to system perspectives and recently, to collaborative approaches within industrial ecosystems. A review identifies 362 practices (Vilochani et al. 2023), reflecting increasing pressures for firms to adapt their product development processes. What is particularly intriguing for our research, is that despite all the practices and implementation guidelines, experts in Sustainable Design notice fixation effects on concepts. Those ones create lock-in situations, instead of tackling new designs with environmental improvements.

2.1.1. Eco-Design methods and tools achievements and lock-in

Eco-Design embodies a proactive approach by integrating environmental considerations early in the product development process, emphasizing measurement, evaluation, and lifecycle analysis (Pigosso et al. 2014). This leads to the development of various Environmental Performance Indicators (EPIs), and the evolution of guidelines, which reflects ongoing efforts to improve the environmental design scope and quality. At the same time, Eco-Design focuses on implementing methods aligned with companies' strategy and maturity levels. (Vezzoli et al. 2008) underline the necessity of understanding companies' processes and assessing a company's knowledge and capabilities before proposing implementation.
However, to uncover unknowns, we must look at the lock-in situations, i.e., blocked situations where progress and innovation are impeded by existing practices. Some researchers and practitioners affirm that there is an inherent limit related to everlasting Eco-Design practices. (Ryan 2013; Ceshin and Gaziulusoy 2016) recall "*Although early implementations of eco-design resulted in huge environmental gains, once the inefficiencies and 'bad design' were removed from products, the gains started to become marginal and increasingly costly, resulting in eco-design becoming problematised*". This limit relies on the choice of functional units for incremental improvements. Indeed, unit environmental efficiency does not prevent from major rebound effects - due to the traditional growth in sales volume business model and increasing consumptions (Ryan 2003). Another aspect that reinforces the limit is the focus on the life cycle. It mostly drives progress in increasing technical environmental performance, but not in reducing other human related impacts, such as changes of usage (Bhamra and al. 2011). In the following development of this paper, we propose to refer to the Eco-Design limit as the 'optimization barrier'. And a proposition to overcome this 'optimization barrier' is by incorporating radical innovation into practices.

2.1.2. Eco-Innovation methods and tools to generate new alternatives

Eco-Innovation, introduced by (Fussler and James 1996), establishes new products and processes that reduce environmental impacts while adding value. Notable examples include applying Eco-Ideation Stimulation Mechanisms (Tyl et al. 2016), combining TRIZ assets or other matrix-oriented solutions (Yang and Chen 2012), and developing Sustainable Business Models (Bocken et al. 2014). These approaches are generally integrated into design processes alongside Eco-Design practices and indicators to generate alternatives. These combined approaches are validated with experimental testing. They have the capability to raise new environmental values, offering a multitude of design options - which could support strategies to overcome the 'optimization barrier'.
We will now consult the packaging design literature to confirm if the 'optimization barrier' applies there, but also if any other fixation effects and blocked situations appear.

2.1.3. Applications in the packaging industry

Examining practical challenges in the packaging industry reveals that diverse sources influence the field development. Among them, LCA studies, central to Eco-Design, yield shared insights:

1. Redesigning product features or life cycles significantly improve environmental performance at the beginning of Sustainable Design applications (Cesgin and Gaziulusoy 2016). This supports designing packaging standards, such as the 'R' principles: Refuse, Replace, Reduce, Reuse, Recycle, and enhances packaging quality.
2. Despite standardization efforts, differing results complicate decision-making due to variations in functional units, databases, environmental impact choices and sometimes awareness gaps. Marine pollution is an illustration of the last one (Kaestner et al. 2023).
3. Designing sustainable products alone is not sufficient to effectively mitigate impacts; challenges persist despite technological advancements. Collective thinking and a shift towards 'Product-Service systems design' are needed for broader transformation (Gatt and Refalo 2022).

We can conclude that packaging lock-in situations ensure consistency with previous observations; there is an optimization barrier with fixations on technological solutions and life cycle concepts. However, even if research leverages Eco-Innovation practices on sustainable business models to promote circular economy principles (Reuse, Repair and Recycle), the business applications seem to be blocked. For example, even considering the positive impact of reusability over dematerialization (Reike et al. 2018), companies are not yet widely adopting Reuse concepts. It unveils a new lock-in, the 'innovation barrier'.

2.2. Inputs from design theory

To answer our question about how to uncover unknowns, at first, we asked: what specific challenges do practitioners encounter, and why are they blocked? And we identified two types of design barriers, the 'optimization barrier', and the 'innovation barrier', which manifest as prominent lock-in situations. They stem from different forms of fixation, such as cognitive fixation in the former and fixation within design deployment in the latter - although this fixation requires to be detailed within our research. Also, in such context, we know that Design Theory insists on managing unknowns to unfreeze design. Distinguishing between uncertainty and unknowns is critical for environmental transition, as (George et al. 2021) explain, emphasizing the exploration of 'unknown unknowns' to construct a state space amid incomplete information. That is why, Design Theory can provide fundamental inputs for achieving sustainable design and facilitating design efforts within the dynamic landscape of environmental transitions.

2.2.1. Fixation effects

In the realm of Sustainable Design, fixation effects play a significant role, particularly in the early phases of the design process. They can influence the selection of methods and tools and vice versa, shaping the generative potential of the design process. Therefore, it is key to consider the impact of fixation effects on collective actions. (Verganti 2008) cautions designers about the risks associated with fixation, especially regarding traditional product representations. (Le Masson et al. 2011) identify three historical forms of fixation: fixation by existing products, fixation by the reuse of irrelevant design rules, and fixation by 'cliché.' (Hatchuel et al. 2011) outline four types of fixation effects: in generating alternatives, in knowledge acquisition, in collaborative creativity, and in the creative process. Moreover, (McMahon et al. 2020) illustrate two probable fixations on solutions for Sustainable Design: 'smart technologies' and 'circular economy'. These are not only fixations on artifacts but also on imaginaries. For 'smart technologies,' designers must decide whether to focus solely on technological solutions, which often involve design trade-offs between performance, environmental impact, and economy. Also, evaluating these concepts adequately remains challenging due to limited knowledge, unknowns regarding adoption consequences and many potential rebound effects. 'Circular economy' focuses on leveraging exclusively existing knowledge, such as changing usage patterns to reduce energy and material consumption. Although it mitigates risk, it heavily relies on mutual consent from the entire population. Finally, these examples underscore the necessity of transitioning from concepts to knowledge through methodological approaches. Even more, it aids in identifying unknowns and forecasting design efforts.

Complementing the caution on fixation effects, Design Theory builds methods upon the recognition and exploration of unknowns. Some of them, stemming from the C-K theory, demonstrate ability to unfreeze designers.

2.2.2. A method to identify unknowns

In this regard, it appears compelling to maintain the perspective of Innovative Design methods, such as the C-K method for studying fixation effects and unknowns related to traditional Sustainable Design mentioned in the first section of the literature review. The C-K method establishes an innovative design model by interacting between a concept (C) space and a knowledge (K) space. Its succession of design operations contributes to expansive exploration of unknowns. We will leverage it in our empirical study conducted within an intermediary with expertise in both traditional Sustainable Design and Innovative Design. This intermediary has integrated and adapted the C-K theory into its method, aiming to (1) develop transition knowledge, and (2) propose the creation of an extensive conceptual landscape.
Building on our literature review, we aim to test two hypotheses about barriers in Sustainable Design. The first suggests that the 'optimization barrier' can be overcome through Innovative Design once identified. The second relies on the existence of an 'innovation barrier,' revealed by Innovative Design during the process of generating new transition concepts. Our action research, conducted with an expert in Sustainable Design methods, including Eco-Design, and Innovative Design, leverages four design missions within the packaging industry, known for its continuing environmental lock-in situations.

3. Methodology

A methodology is built to identify the common fixation effects in the four packaging companies and to uncover unknowns related to environmental transitions. Action research with the intermediary named Stim, marks the convergence of three dynamics: (1) development of Sustainable Design practices, (2) firms' requirements to shift environmental performances into higher gears, (3) challenges of lock-in design situations in the packaging industry. Firstly, we will describe the context and the suitability of the packaging missions completed by Stim, then we will explicit the qualitative methodology.

3.1. A unique action research industrial field with a consulting company having experimented four packaging innovative design missions

Stim is composed of Sustainable Design experts leveraging the C-K method. With extensive experience with R&D departments, they are used to identify fixations, provide actionable insights, and generate new alternatives. Their 'Map, Generate, and Plan' process in (Figure 1), was applied across all four missions.

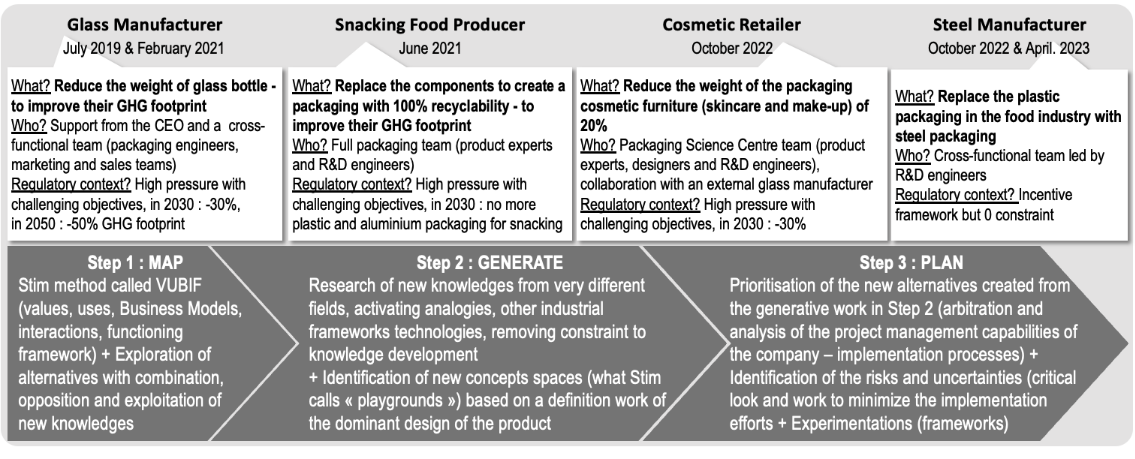

Figure 1. Context of the four design missions led by Stim with international packaging companies

In addition to this unique design method applied by Stim, we choose the missions depicted on (Figure 1), due to their shared characteristics: (1) They operate within a single ecosystem facing regulatory pressure with ambitious targets. (2) They involve international leading manufacturers with global operations. (3) The missions are led by similar stakeholders within the companies, most of the time packaging and R&D engineers. (4) Among these stakeholders, there are Eco-Design experts with practical experiences. That is why, with this consistency, our aim is to evaluate similarities to validate our previous hypotheses. It is noteworthy that our focus is not on assessing the already integrated practices and their effectiveness, but on identifying the current lock-in situations the companies encounter, necessitating an innovative design mission with Stim.

3.2. A qualitative research methodology

Now that the context and the choice of the packaging missions are elucidated, we propose a qualitative methodology to characterize when and why the stakeholders are blocked. Our proposition relies on the combination of two qualitative sources of information. On one hand, interviews conducted with Stim's project managers/designers who completed the missions; on the other hand, systematic reviews of the design process and their insights. In the next two sections, we will detail the research methods.

3.2.1. Interviews and identification of fixations

With the objective to maximize the information retrieved from qualitative interviews, we prepared a set of questions which can help identify fixation effects within the companies' stakeholders. It is indirect analysis as the answers were collected from 12 Stim project managers/designers' interviews. Our area of interests included: Why / how the Stim missions were initiated with the packaging companies? What environmental benefits could be derived from the missions and why? So, we developed a framework comprising 'input' and 'output' parameters. About the 'input' parameter, three subsections were identified during brainstorming sessions with a Stim method expert: (1) Entry Channel: how the mission was initiated within Stim and the associated sales procedures. (2) Needs and issues: how the stakeholders articulated their transition needs and issues. (3) Mission Scope and General Structure: how interactions defined the mission goals and scope. For the 'output', a similar process was followed, resulting in three other subsections: (1) Selection of New Concepts: what interactions and rationales led to concepts selection. (2) Implementation of New Concepts: what activations could create direct and indirect values (concepts generated side effects, knowledge, and expertise). (3) Reintegration of New Environmental Transition Concepts in the Ecosystem: what outcomes spread out within companies and for the broader industrial ecosystem. In each subsection, identical questions were posed, including inquiries about how the prospect initiated contact with Stim, the nature of their contact person, expressed client needs, monitored environmental characteristics, client expectations for mission success, concept evolution throughout mission, final concept selection rationale, potential for reusing concepts or innovative fields, acquisition of new sector-specific expertise, and transfers of innovation or final concepts to other entities within or beyond the company's ecosystem. The interview procedure remained consistent across all 12 sessions, with each lasting one and a half hours per person per mission, conducted via video conference with manual notetaking. Transcription and coding followed a methodological approach inspired by (Gioia et al. 2012), involving word-concept association, thematic grouping, and result aggregation based on dimensions, which align with interview subsections and missions' process phases.

3.2.2. Reverse engineering and gap analysis

The reverse engineering method relied on another source: the content of the design missions themselves, based on the productions of the project managers/designers. We leveraged it through two stages.

Firstly, we synthesized the results and highlighted the learnings for each phase of the 'Map, Generate, Plan' missions, which were documented through procedures, databases, deliverables. These learnings intersected with those from the qualitative interviews - as parameters and subsections also follow the course of the missions. We could elucidate the phases involving the selection and exclusion of concepts, as well as the phases involving the evaluation of the environmental performance.

Secondly, we analyzed the generativity gap between the initial concepts tested by the manufacturers before the missions and the final concepts selected by the stakeholders of the companies at the end of the missions. We chose two evaluation parameters: (1) transformation of the initial solution, and (2) renewal of the expertise (from a technical nature). The first one referred to the transformation of the solution for its value, usage, and business model dimensions - compared to the dominant design (i.e.,

the existing product and reference on the market) - while the second one referred to the renewal of expertise for products and manufacturing process dimensions, involving mainly technical alternatives.
Finally, the reverse engineering process, coupled with gap analysis, will aid in identifying fixations and revealing unknowns within packaging companies. Furthermore, it will offer valuable insights, as our examination of rejected concepts will shed light on another type of fixation effect - which is inherent to Innovative Design for environmental transition.

4. Data analysis and findings

The results aim to review fixation effects associated with Sustainable and Innovative Design, leading to both the 'optimization barrier' and the 'innovation barrier', which may not align with the environmental transition targets articulated by the packaging companies. Therefore, uncovering unknowns, intricately tied to fixation effects, should help assess the lock-in situations they encounter.

4.1. Uncovering an optimization barrier

At first, the interview analysis highlights cognitive fixations in two different areas: stakeholders' existing technological and environmental knowledge, and formulation of objectives for environmental transition, all indicating the use of Eco-Design methods/tools. Then further examination of missions' phases, along with generative extension activities, reveal unknown transition factors. These underscore the presence of an 'optimization barrier' in the Sustainable Design practices of the packaging companies.

4.1.1. Revealing fixation effects

The revelation of fixation effects stems primarily from the combined analysis of the 'input' parameter coding and the reverse engineering. A first fixation type emerged prominently with 30 instances across interviews, denoted as a technological fix. The stakeholders of the packaging manufacturers consistently favoured engineering and technology to address environmental challenges. This inclination manifested in various forms, including a preference for technological solutions within the creative process of innovative design. Notably, during the mission's initiation phase, the Steel Manufacturer stakeholders exhibited a strong resistance to non-technological approaches. Also, during the 'Map' phase with external knowledge search, the Glass Manufacturer stakeholders requested the Stim designers to keep looking for advanced technological processes like pressure moulding, injection moulding, forming of pharmaceutical bulbs, production of Gorilla Glass for smartphone screens, and the development of composite materials. Yet this phase is supposed to lead exploration of unconventional knowledge from other industrial activities. Interestingly, this fixation could not be solely attributed to the stakeholders' R&D profiles, as some teams comprised mixed profiles, and innovative design missions historically broaden the scope beyond technical solutions anyway. A second fixation type centres on life cycle assessment, as the theme emerged 22 times during the interviews. For instance, the Snacking Food Producer stakeholders expressed their needs - predominantly based on material footprints and prior LCA results, emphasizing the positive impact of fully recyclable cardboard packaging. The fixation effect is linked to the choice to maintain the same functional unit (i.e., individual single-use packaging) and the purpose to improve the end-of-life recyclability. The stakeholders' fixation on LCA guided the selection of solutions, generally focusing on the type of solutions based on the raw material knowledge and the well-integrated Eco-Design processes. Moreover, fixation effects on LCA often led to fixation on 'R' macro-concepts, concepts aimed at improving product environmental impacts, such as 'Replace' and 'Reduction'. They aimed to reduce the environmental footprint of product life cycles. Two examples are: the substitution of plastic/aluminium packaging by cardboard packaging, and the reduction of the glass bottle and cosmetic packaging weights. Both are already orientated towards specific solutions whereas the actual problem is reducing the GHG footprint to conform to the regulation. In these cases, we can see that fixations on macro-concepts can restrain the design space from the outset of the missions.
Our methodology confirms the pervasive influence of fixation effects (technological solutions and LCA), resulting from traditional Sustainable Design practices. Also, analysis of the packaging case study revealed that cognitive fixations sometimes led to inadequate problem framing during the scoping phase, persisting throughout the innovative design missions.

4.1.2. Identification of unknowns

The second stage of the reverse engineering methodology is the gap analysis between the initial concepts and the generated concepts. It highlights the fixations in the eyes of the stakeholders and uncovers unknowns of Sustainable Design, by contemplating the nature of the alternatives and examining the design factors' differences before and after the C-K method application. (Figure 2) displays the 'primary packaging concepts', developed by the manufacturing companies before the innovative design missions, and the 'extended packaging concepts', generated with the method and selected by the firms.

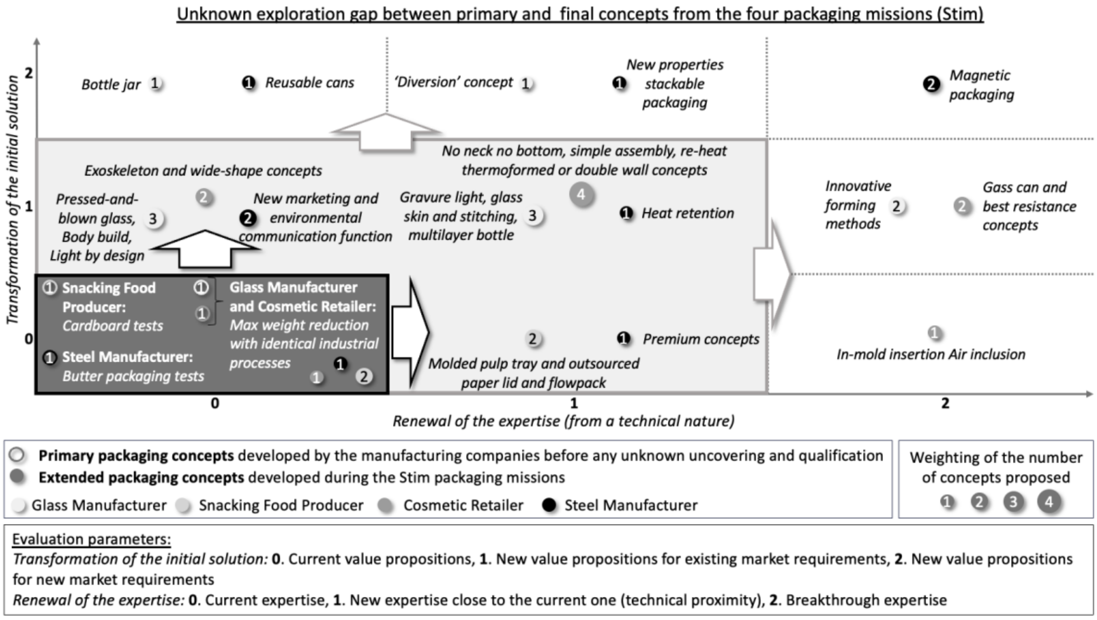

Figure 2. Matrix of the new environmental concepts generated via the C-K method for the packaging study

Before the missions, the stakeholders had one concept developed/tested for their expressed issues and after the missions, they had from 10 to 16 concepts generated, and 4 to 8 selected. What is particularly interesting in (Figure 2) is the widening capability of the method, with limits of the original design spaces being exceeded. The matrix maps these concepts according to (1) their value transformation power and (2) their technical renewal capability. Both integrate numerous additional design factors and unknowns. It is noteworthy that the anticipated design ideas of the packaging firms fall within the 0 to 1 range on both axes of the matrix. Their space is represented by the black-framed box. On the horizontal axis, '0' represents mainstream product evolutions over the past decade; for example, substituting PVC for PET. '1' displays product evolutions gaining popularity, such as ocean plastic waste as a recycled sourcing component. '2' denotes ongoing topics of scientific research or protected by patents, thus qualifying as cutting-edge technologies. Thus, any expansive generation towards the right side of the horizontal axis qualifies for breakthrough innovation, i.e., new advanced technological assets. On the vertical axis, a transformation of the product value is evaluated: '0' embodies dominant designs value propositions, '2' at the top of the axis contributes to a real transformation of the traditional business model or a radical redesign of the usage of the product. For instance, these disruptive innovations can involve the implementation of circular business models. Please note that the unknowns are made visible on the concept matrix, but they are revealed by the generative process itself. For example, when looking to reduce the glass weight for the Cosmetic Retailer, designers discovered that the neck was a major weight spot, and that resistance constraints were not valid if the closure system was reinvented too. The process - alternating between C and K spaces - led to a 'neckless glass pack' concept. In this case, new top closing systems were revealed as design unknowns. Therefore, the C-K method orchestrates the uncovering of some fixations upstream in the packaging mission phases (during the 'Map' and 'Generate' phases), but also characterize unknowns thanks to its ability to identify them and place them on an

extensive map of concepts. The expansion is depicted by the white arrows in (Figure 2). Passing from the black framed box to the white box represents the overcoming of the 'optimization barrier'.
In summary: (1) Fixation effects were confirmed in Sustainable Design, particularly in technological and life cycle assessment areas. (2) An Innovative Design approach tackled them and introduced new alternatives. Although our first hypothesis regarding overcoming the 'optimization barrier' is validated, further examination is required to warrant the second hypothesis. Moving forward, we will focus on concepts selections/rejections rationales, drawing from interview outputs and reverse engineering.

4.2. Uncovering of another design barrier

Stim experts leverage two transformational axes when designing companies' transition. On (Figure 2), we not only observed an expansion with breakthrough innovation (horizontal axis) but also disruptive innovation (vertical axis). However, many concepts with high environmental potential are not launched. Firstly, we will look at the reasons for not selecting them. It shall inform us about the variable design efforts they underpin. Secondly, we will characterize another lock-in revealed by the Innovative Design.

4.2.1. Differentiation of the design efforts

The interview coding lists 14 references about the non-selection of concepts related to transforming the offer, which includes reinventing the value proposition, the end-user's usage of the product, or the product's business model. These concepts, often in level '2' of the matrix contain more unknowns, as they are much more distanced from the origin of the space, i.e., the dominant design.

2 Concepts not selected	Descriptions and Characteristics	Why were they not selected?
Glass Manufacturer: for the case of glass bottles filled with beverages	**(1) Glass bottle which changes the usage for final consumers,** means the consumer's usage is reconsidered to reduce packaging constraints. *No characteristics developed.* **(2)Glass bottle with less technical constraints standards**, is lightened through challenging the design standards (capacity, diameter, opening, etc.). *No characteristics developed.*	The concepts regarding the business model, usage, life cycle adaptation, and reduction of resistance were excluded during the design mission. The stakeholders had **no assignment outside of technical breakthrough or design changes**.
Snacking Food Producer: for the case of packaging for dips and breadstick **(1) Bulk Snacking Food** **(2) Nudging Packaging**	**(1) Bulk snacking food**, refers to separate sales of dips & breadsticks. *<u>Characteristics:</u> This approach increases the ratio of dips and breadsticks per secondary pack, potentially reducing environmental impact at scale. It requires changes in the distribution chain and may alter the business model, involving the Snacking Food Producer's supply chain, quality control, marketing, and sales teams.* **(2) Nudging packaging for snacking food** involves employing packaging in an educational and playful manner to promote a more sustainable end-of-life scenario. *<u>Characteristics:</u> This approach combines fun and education to encourage new consumer behaviours supporting zero-waste outcomes. It entails new usages and involves the Snacking Food Producer's communication, marketing, and sales teams.*	Most proposed packaging concepts (recycled materials, biodegradables) were excluded, leaving only 100% recyclable options. Similarly, concepts regarding the value chain were set aside. Ultimately, the retained concepts focus on materials and assembly processes in factories, emphasizing engineering or technical innovations. The stakeholders' main **constraints were maximizing the use of existing industrial machinery in the factory manufacturing process.**
Cosmetic Retailer: for the case of cosmetic cream glass packaging **(1) The Do-It-Yourself formula Glass Pack** **(2) The '0' Supply Chain Constraint Glass Pack**	**(1) The Do-It-Yourself formula Glass Pack,** contains a solid and condensed active formula to be reconstituted directly by the customer. *<u>Characteristics:</u> This concept offers a redesigned glass pack for consumers who want to customize their products by adding water, oil, or other natural ingredients themselves. This reduces the pack versus active formula weight ratio and involves consumers in preparation and personalization steps. Further development would require alignment with strategy, marketing, formula cosmetic R&D, and sales teams.* **(2) The '0' Supply Chain Constraint Glass Pack,** is optimized for the distribution of creams purchased online exclusively. *<u>Characteristics:</u> This concept removes physical distribution constraints and paves the way for an e-commerce-friendly business model, including subscriptions or package deals. As it requires changes in purchasing habits and business models, it involves strategy, marketing, and sales teams.*	The stakeholders have selected Glass R&D concepts for investigation in the project phase: ultra-thin glass pack (already scoped within the packaging R&D team prior to the mission), assembled glass pack, and composite glass pack (with a team of designers for hypotheses and tests). They also proposed some **concept recoveries related to design coordination with other departments**, but the follow-up remains unconfirmed. Concepts beyond design considerations, like DIY and '0' Supply Chain Constraint proposals, were **excluded early in the 'Map' phase without discussion of recoveries or interest**.
Steel Manufacturer: for the case of food supply packaging (plastic to steel) **(1) The Reuse Steel Packaging** **(2) The Refill Steel Packaging**	**(1) The Reuse Steel Packaging,** is leveraged if steel become one of the key materials in tomorrow's reuse solutions. *<u>Characteristics:</u> Steel offers advantages for reuse due to its strength and lightness, despite varnish resistance being a technical challenge. Another challenge lies in identifying most relevant use cases for steel, such as lightweight and dry products like cereals. Reuse concepts present challenges for stakeholders as they involve changing business models and customer usage patterns. Further investigation would involve marketing, sales, and R&D (for technical aspects) teams.* **(2) The Refill Steel Packaging,** means that steel plays the role of the material that fits optimal recharges. *<u>Characteristics:</u> There are several paths to explore for steel, including the 'Russian doll' bulk container, steel drums, aerosol refills, and 'clean' refills. Identifying the most relevant use cases for steel remains a key challenge. Implementing usage changes would require collaboration among marketing, sales, design, and R&D teams.*	As the primary objective of this mission for the stakeholders was to gain market share by replacing plastic packaging with steel packaging, the selected concepts do no really bring environmental improvements. The 3 concepts preselected by the stakeholders are: Nomadism (packaging with heat retention for meal delivery), Transformation (Reheat capacity on stovetops and in ovens), Safe-Box (biscuit or chips dispenser tube). The concepts of Reuse or Refill are not considered as **they do not address the challenge of selling more steel packaging, which remains the company's primary and unchallenged business model**.

Figure 3. Examples with the four packaging innovative design mission of non-selected concepts

Consequently, we can suppose that they require major design efforts for the packaging companies, who lose interest in prioritizing them to improve their environmental impacts. For instance, in the upstream part of the innovative design process, during the 'Map' phase, the Glass Manufacturer had already ruled out questioning the business model (selling glass by weight, which leads to increasing glass bottle sales, even though the environmental impact per unit is assumed to decrease). Additionally, stakeholders from the Glass Manufacturer had chosen to outright exclude all concepts related to bottle deposit systems, as they did not meet their need for breakthrough innovation. As seen with the fixations, preferred design efforts are centred on breakthrough design, with renewal of the technical expertise, but not on the transformation of the offer. (Figure 3) illustrates few other packaging examples from the missions which were rejected - this time during the 'Generate' phase. A design deployment barrier appears related to variable design efforts, due to constraints of various nature. Some reasons prevails that the concepts are out of R&D scopes and without capability to coordinates concept recoveries in other departments of the packaging firms. This represents well the lock-in situation mentioned in the literature about the Reuse concepts which were not enough rolled out within projects despite huge positive environmental impacts.

4.2.2. Qualification of an innovation barrier

What is striking is that while applying Innovative Design to overcome the 'optimization barrier', we encounter another challenge related to the non-deployment of disruptive concepts. This suggests that different types of fixations arise during the innovative design process, one of them assumes that stakeholders would act upon any uncovered unknowns and concepts resulting from the missions. If these were beyond their initial scope, they would collaborate with other teams or actors to develop the generated concepts. So, these non-selected concepts reveal a new type of barrier: the 'innovation' barrier, which is not cognitive, but process based. It exposes a biased innovative design process favouring 'disruptive' over 'incremental' concepts, asserting that the latter are incapable of achieving higher environmental performances - demanded by the packaging companies. (Figure 4) illustrates the presence of this second barrier, which operates in a distinct design space from the 'optimization barrier'. While the latter is characterized by a gradual decline in environmental performance over time, the 'innovation barrier' relates to the difficulty in implementing new transition concepts with significant environmental impact. The more potential they hold, the more challenging they can be to implement, especially as the design efforts are not clearly understood or mastered, hence their activation are blocked. Drawing on different design spaces with their respective axes, we have depicted the design curves that define these two barriers. They are independent of each other and coexist simultaneously. Our experimentation with Stim in Innovative Design reveals that the packaging manufacturers from the case study have overcome the 'optimization barrier', yet the missions have exposed the 'innovation barrier'. It is worth noting that the latter existed previously but was not discernible until innovative design application.

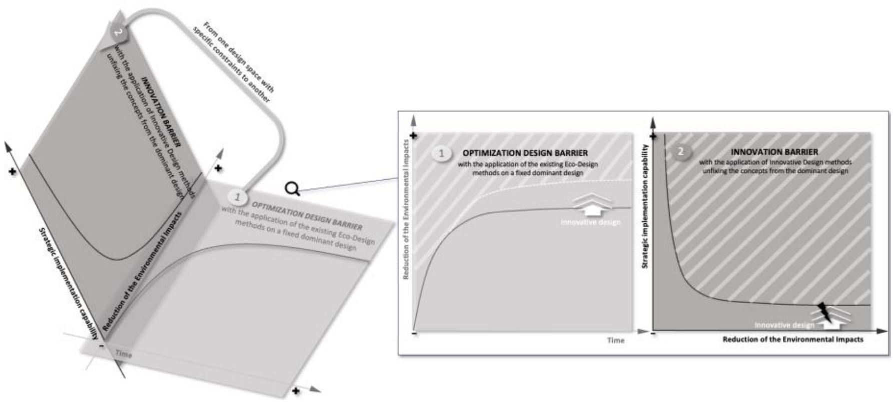

Figure 4. Design spaces blocked by the optimization barrier and the innovation barrier

5. Conclusion and discussion

In conclusion, we have seen in the literature that companies proficient in Sustainable Design and more specifically in Eco-Design, encountered the 'optimization barrier'. This barrier has been confirmed from our experimentation, plus perceived by the packaging stakeholders. At the same time, upon adopting Innovative Design processes, the 'innovation barrier' has emerged when disruptive concepts failed to materialize into tangible projects. To move forward, it is imperative to devise a method for overcoming the 'innovation barrier', akin to how Innovative Design surpassed the 'optimization barrier'. We would like to discuss it from this point forward: exploring ecosystem-level challenges and gaining deeper knowledge into other industrial actors' challenges. Our new hypothesis is that this ecosystem knowledge expansion shall be key to identify and effectively activate design efforts for disruptive concepts. It shall require new action logics for which innovative transition intermediary may play an important role, to diffuse them while connecting the ecosystem actors all together.

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