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Driving sustainability in packaging design | The development of a framework to guide the transition towards a sustainable future

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This thesis looks into the different challenges regarding the transition towards sustainable packaging. This is necessary since the increasing demand for sustainable packaging has compelled companies to undertake steps and innovations in this area, aiming to transition their product portfolio towards more sustainable packaging options. However, sustainability is a sophisticated and a complex concept, and there is no single universal method or measurement to address it. In this research, the triple-bottom line approach to sustainability is employed as the foundational basis. To assist the packaging developers in this transition, a framework is developed. This framework consists of multiple layers that provide design directions, as well as identify limitations and challenges associated with the identified approaches. The framework is verified and validated through a case study. The case study involves the development of a theoretical draft redesign for an existing packaging within a specific Unilever portfolio, following the prescribed framework.

Packaging design, Sustainability, Framework

1. Introduction

In recent years, there's been growing concern about the environmental impact of packaging, leading companies to shift towards more sustainable solutions. However, achieving sustainable packaging design is challenging due to various factors. The process is constantly evolving with new technologies and innovations. During the transition to sustainable packaging, the goal is to maintain packaging's purpose and quality while reducing its environmental impact.

Successful examples of sustainable packaging exist, but they can't be directly applied to all cases. To support designers, sustainable frameworks have been developed, but they may be limited or too general, lacking the necessary guidance to address complex situations faced by packaging developers. Additionally, packaging is mostly considered as waste as consumers mainly care about the product in the packaging. However, at the same time, a certain level of convenience of use is expected from the user which should be adhered to, as well as the stringent regulations in place

Consequently, this thesis aims to address two main objectives. Firstly, it aims to translate sustainable strategies into a design consideration framework that can guide packaging developers throughout the design process. Secondly, it seeks to explore possibilities for enhancing the sustainability and cost reduction of rigid plastics in the EU savoury portfolio of Unilever, by applying the developed framework. The focus of this thesis will be on packaging intended for retail markets.

2. Application of packaging

Products that require packaging are referred to as Product-Packaging Combinations (PPCs), which are for example, found in the Fast-Moving Consumer Goods (FMCG) sector. These PPCs can be classified into five distinct groups: food, drugs, non-food, durables, and industrial goods [1]. Each group has specific vulnerabilities, necessitating tailored packaging solutions to ensure adequate protection. Consequently, a universal packaging solution applicable to all PPCs remains elusive.

The life cycle of a PPC involves the utilisation of various packaging types, collectively referred to as the packaging system [2]. This system comprises three levels: (1) primary packaging, (2) secondary packaging, and (3) tertiary packaging.

2.1. Purposes of packaging

Packaging fulfils numerous aspects, next to the key duty of protecting the product during transportation and until it reaches the consumer's household. Packaging should provide essential information to the consumers, enhancing their overall experience, and ensuring convenience of use. The main functions of packaging include: (1) protection and preservation, (2) identification, (3) containment, and (4) conveyance [1, 3-6].

2.2. Packaging materials

Selecting appropriate materials for packaging is crucial to ensure proper protection and maintenance of product quality. The commonly used (traditional) materials for packaging include glass, metals (such as aluminium and tin), paper and paperboards, and (fossil-based) plastics [4]. In addition, an upcoming material and in constant development are the bioplastics, their development holds promise in enhancing the sustainability of PPCs.

3. Sustainability in the context of packaging

The concept of sustainability is complex and multifaceted, and as such, one could argue that there is no single, definitive definition of what sustainability truly entails. This is because there are several different and varying perspectives of what sustainability indicates [7]. Moreover, sustainability whether in relation to a product or packaging, is not absolute, but rather, it is a multidimensional concept. As a result, there is no single, universal measure of sustainability.

Typically, the triple-bottom line approach is utilised to define organisational sustainability; (1) environmental, (2) economic, and (3) social [8] (fig. 1.).

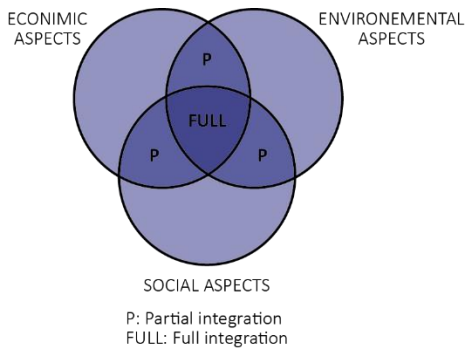

Figure 1.; *Sustainability represented through a Venn diagram – adapted from [8]*

3.1. Circular economy approach

The circular economy represents an encompassing approach aimed at transitioning from linear resource consumption to circular resource loops. It involves three fundamental strategies for resource cycles: (1) the reuse of goods, (2) recycling of materials, and (3) resource efficiency to reduce resource consumption [11]. These strategies can be categorized as R-indicators and align with the sustainability mantra in packaging design; *Reuse, Reduce, Recycle* [12].

3.2. Reduction

Narrowing resource loops through prevention and reduction is essential to improve the linear progress of packaging design. Eliminating unnecessary packaging material is particularly effective as it prevents the generation of waste during the packaging life cycle.

Reduction can also be used on the product side of the PPC, as in general the product has more significant environmental impact than their packaging [13]. Therefore, considering the packaging and product as an integrated system is essential, as the design choices for packaging can influence potential product losses throughout various stages of the PPC life cycle [5, 9, 10] (table 1.).

Stages in life cycle	**Reasoning**
Distribution, retail, and transport	• Poor barriers or physical protection • Unsold; Not attracting the consumer with packaging design • Deterioration or exceeding expiration date • Problems during filling process, e.g., sealing failure
Use phase (consumers)	• Inappropriate product sizes • Product spilling, due to inadequate opening/dosing mechanism • Difficult to complete empty or access the packaging • Decrease in quality of the product, insufficient protection by barrier(s)

Table 1.; Overview of different product waste types due to the packaging design [3,5,10,13,14]

3.3. Recycling

Recycling contributes to sustainable packaging by prolonging the lifespan of resources. However, the recyclability of packaging materials depends on their specific recycling processes with unique limitations and considerations. Therefore, the design of a PPC plays a crucial role in determining its recyclability, referred to as the technical recyclability of a packaging. Designing a PPC with high technical recyclability is crucial for effective recycling. Yet, it is equally important to assess the actual recycling rates of packaging. Adequate waste infrastructure, including collection and recovery systems, plays a crucial role in successful recycling, but its availability varies among countries and packaging formats. The World Packaging Organisation (WPO) provides a shortlist of documents that list the recyclability of materials/formats in specific countries[1]. Moreover, consumers behaviour also affects recycling outcomes, as incorrect disposal can impede recycling efforts [10]. Therefore, clear communication towards consumer is needed, as consumers act to their knowledge and capabilities.

Design for recycling is important to increase sustainability, as using recycled materials further enhances the environmental aspect of sustainability. However, the (currently) finite life cycle and fluctuating availability and costs of recycled materials for most materials pose challenges [15].

3.4. Reuse

Reusable packaging systems are complex due to the involvement of diverse indicators and factors. To effectively address reusable packaging, it should be regarded as a comprehensive system, that incorporates the aforementioned approaches. Four distinct categories are considered within reusable packaging: (1) Refill at home, (2) Refill on the go, (3) Return from home, and (4) Return on the go [16]. Additionally, designing reusable packaging necessitates additional requirements compared to the single-use packaging (SUP) variants. Durability is a critical consideration to ensure the packaging maintains its quality throughout multiple use cycles. Additionally, the shape and size of reusable packaging serve the extra purpose of facilitating ease of cleaning compared to SUP variants [17].

3.5. Consumers

The role of consumers in achieving sustainable packaging solutions can be viewed in two aspects: (1) their willingness to pay for sustainable solutions, and (2) their influence on the end-of-life stage of a packaging [18,19]. Thus, to achieve sustainable solutions, packaging designers must aim to reduce the environmental impact of the PPCs over their entire life cycle while also considering consumer preferences and behaviours. This can be challenging, as consumer preferences and behaviours may not always align with sustainable designs, potentially leading to decreased sales and economic unsustainability, resulting in short-term product losses [19]. Transitioning from SUP to reusable packaging necessitates behavioural changes from consumers, as they need to participate in refilling or returning the packaging, introducing additional steps during the use phase of the PPC.

4. Framework analysis

Various frameworks and methods have been developed to guide the implementation and understanding of sustainability in packaging design. However, sustainability and packaging are broad concepts, leading to diverse strategies and considerations. Consequently, the existing frameworks exhibit varying scopes and areas of emphasis. Some frameworks concentrate on specific aspects such as food packaging, while others centre on consumer perceptions or encompass the entire packaging supply chain.

Based on the strategies identified through the analysis and their alignment with the earlier explained R-indicators, the main used strategies for integrating sustainability in packaging are as follows:

- Optimising resources use
- Renewable materials
- Design for recycling
- Minimise product losses
- Efficient palletisation

[1] https://www.worldpackaging.org/wpo/45/

These strategies will serve as the foundation for the proposed framework, although not necessarily in the exact order or terminology used. Furthermore, the done analysis showed that the current reviewed frameworks fall short in adequately addressing the other aspects of sustainability, such as economic and social considerations. Additionally, these frameworks do not always incorporate explicit design directions or consider potential consequences and trade-offs associated with a specific strategy. Thus, the proposed framework seeks to address these limitations and provide a comprehensive approach to the strategies.

4.1. Development of the framework

The framework is designed to be applied to primary packaging, however the consequences of the primary packaging on the entire packaging system will be acknowledged and encountered. It is intended that the of the framework is used as an exploratory step in the initial stages of (new) projects. It provides various directions for developing draft packaging solutions, which can then be evaluated to identify the most promising option(s), to be used as starting point for a project. The outcome(s) of the framework should be subjected to further evaluation through additional tests, such as consumer testing, shelf-life testing, and strength testing.

The development of the framework is based on existing frameworks, but it introduces an additional layer for each strategy, providing more information and starting points for consideration, as well as highlighting the consequences some implementation could have (fig. 2.). The base layer presents the sustainable strategies that can be considered for improving the sustainability of a packaging format. Providing the users with the possibility to specifically focus on one of the strategies and choose whether to explore the sublayer. Each sublayer provides further guidance and insights for implementing the chosen strategy.

The framework allows flexibility in its use, without suggesting a fixed order or hierarchy to follow. Instead, it offers guidance on the various strategies and their potential benefits and trade-offs, allowing the user to determine the most appropriate sequence or combination based on their specific needs and goals.

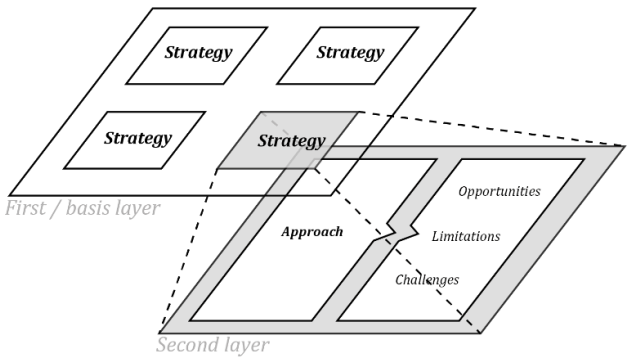

Figure 2.; The structure of the identified layers in the framework

5. Sustainable packaging design framework

This framework includes references to external tools and guidelines that can be used alongside the framework for more detailed information at specific steps (fig. 3.). By using this framework, packaging professionals can identify potentially promising design directions based on theoretical data and (simplified) life cycle assessment (LCA) outcomes. Furthermore, it can aid in the development of a long-term vision by incorporating multiple sustainable directions, thereby enhancing the sustainability performance of a packaging format over time. The framework is based on the defined strategies and emphasises the absence of a hierarchical order among them, allowing and encouraging for the exploration of various scenarios rather than solely focusing on one strategy. However, users have the flexibility to establish system boundaries that may lead to a more concentrated focus on one specific strategy.

During the design process, conflicts may arise, such as defining the environmental targets (e.g., balancing climate change mitigation with biodiversity preservation) or conflicts with other packaging requirements (e.g., convenience of use, marketing aspects). Addressing such conflicts requires making trade-offs to determine the preferred design direction. There is no universal solution for making these trade-offs, as they contingent upon the brand and market in which it operates.

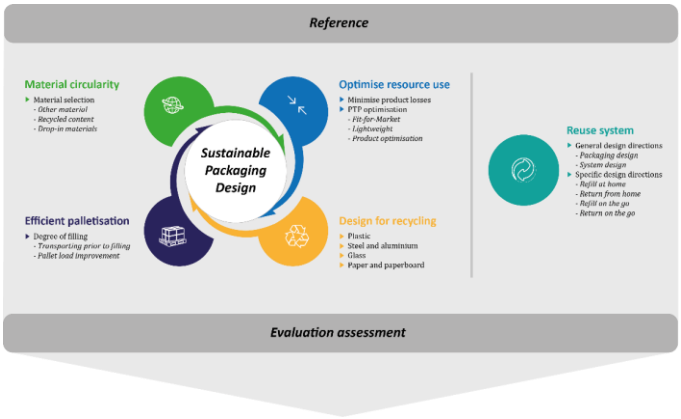

Figure 3.; The basis (first layer) of the framework

Each strategy identified in the base layer is explained in more detail in the second layer of the framework. The strategies identified in the framework are as follows:

- **Material circularity;** *Alternative material, Recycled material, Bio-material.*
- **Optimise resource use;** *Minimise product losses, Product-to-packaging (PTP) optimisation.*
- **Efficient palletisation;** *Transportation prior to filling, Pallet load improvement.*
- **Design for recycling;** *Plastic, Aluminium, Glass, Paper.*
- **Reuse system;** *General design directions, Specific design directions.*

For the evaluation assessment, two different methods are proposed: (1) Integration analysis, and (2) Eco-cost/real value (EVR) method. The integration analysis can be useful when a different packaging format is considered, which could have an effect on the functionality. The method aims to identify packaging solutions with the highest eco-efficiency, where eco-efficiency is identified as creating more value with less impact, defined by the ratio of functional performance to environmental impact [20].

The EVR method is employed to assess the consequences of a (packaging) design on the economic and environmental aspects [21]. The eco-cost serves as an indicator of the environmental consequences of the packaging design. Multipliers can be used to convert emissions equivalent (e.g., acidification, global warming) into eco-cost. The price consumers are willing to pay or currently paying for a product can be used as measure for real value.

6. Case study

To validate the developed framework a proof of concept will be conducted in the form of a case study. To determine the appropriate packaging format for the case study, a portfolio analysis was performed for a niche department within Unilever. As a result of the portfolio analysis, and currently ongoing projects at Unilever, the Knorr aromat sprinkler is selected as the subject of the case study.

To begin, the current situation of the packaging needs to be defined before applying different strategies to seek sustainable

solutions. This format will undergo all the proposed strategies within the framework to identify potential solutions. The Knorr sprinkler compromises a can with an in-mould label for decoration and a cap, both made of polypropylene (PP).

6.1. Evaluation assessment Knorr aromat sprinkler

The assessment of the various draft solutions from the framework was conducted using an LCA modelled in GaBI to measure the environmental aspect of sustainability. The functional unit (FU) used for the LCA is defined as *"To pack 88 grams of aromat powder per unit, at a total of 20 million units"*. The FU is set to the certain sales volume, but the LCA is modelled on the amount of filling one truck, to ensure comparison with the efficient palletisation strategy.

The different draft solutions show potential for short-term and long-term improvements. Chemical recycled PP (cPP) and bio-PP can potentially be implemented without requiring a redesign for the packaging format. Along with some changes of the collation of primary packaging in secondary packaging, which allow for more efficient transportation. For the long-term, potential implementations include changes in the dimensions of the can to reduce material usage and improve transportation efficiency, as well as the implementation of a redesigned cap that utilises fewer materials. These changes have the potential to enhance the sustainability of the Knorr aromat sprinkler in both the short and long term.

7. Conclusion

The conclusion provides answers to the two main research questions based on analysis and developments. The study's foundation includes preliminary research on sustainable packaging design and the development of a guidance framework. The case study focused on the sprinkler format and suggested pursuing design directions that include implementing recycled and biobased materials, while also reducing material usage. However, these directions require testing and verification due to uncertainties.

Regarding cost-effectiveness, reducing material usage is the most favourable solution, but consideration of consumers' willingness to pay for sustainable options is essential.

The framework serves as a guiding tool for packaging developers, outlining various strategies and evaluation methods. It allows flexibility and adaptation based on individual expertise and project characteristics. While the case study revealed trade-offs and decision-making moments, the framework currently lacks comprehensive guidance in complex situations.

Overall, the framework empowers users to make informed decisions and explore multiple strategies to achieve the most sustainable solutions for their packaging projects. However, further enhancements are needed to better support decision-making in divers packaging contexts.

8. Discussion & Recommendations

The application of the framework at the initial stages of the design process may lead to potential rejections of outcomes after required test, due to unsuitability for specific PPCs or target markets. However, the framework efficiently manages project time by exploring multiple approaches before delving into specific solutions. Enhancing the framework's implementation necessitates additional specifications and aspects for extension.

To streamline the framework, it is essential to provide guidance for checking functional and technical requirements, as well as assessing consumer acceptance. The interpretation of results and potential combinations of draft solutions require revision, prompting the need for a more comprehensive approach. This involves considering interdependencies, feasibility, and trade-offs between solutions, empowering users to optimise sustainable outcomes. Moreover, establishing a connection between the framework and packaging claims and conducting diverse case studies will enhance its value and applicability, thus contributing to the advancement of sustainability in packaging.

Despite the absence of a hierarchy among strategies in the framework, it recognises the complexity of sustainability and unique requirements of PPCs. However, certain interdependencies among strategies may naturally create a hierarchy, considering the impact of material switches on recyclability and the influence of technological advancements and circular economy principles. Although the framework's flexibility allows for diverse interpretations and creative approaches, it may pose challenges in achieving consistent sustainable outcomes, underscoring the intricate nature of sustainability in packaging design.

References

[1] ten Klooster, R., 2002, Packaging Design; a methodical development and simulation of the design process, Delft University of Technology.

[2] Pålsson, H., Hellström, D., 2016, Packaging logistics in supply chain practice–current state, trade-offs and improvement potential. International Journal of Logistics Research and Applications, 19/5:351-368.

[3] Pauer, E., Wohner, B., Heinrich, V., Tacker, M., 2019, Assessing the environmental sustainability of food packaging; An extended life cycle assessment including packaging-related food losses and waste and circularity assessment, Sustainability, 11/3:925.

[4] Marsh, K., Bugusu, B., 2007, Food packaging—roles, materials, and environmental issues, Journal of food science, 72/3:R39-R55

[5] Wikström, F., Williams, H., Verghese, K., Clune, S., 2014, The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies - a neglected topic, Journal of Cleaner Production, 73:100-108.

[6] Wohner, B., Pauer, E., Heinrich, V., Tacker, M., 2019, Packaging-related food losses and waste: an overview of drivers and issues. Sustainability, 11/1:264.

[7] Santi, R., Garrone, P., Iannantuoni, M., Del Curto, B., 2022, Sustainable Food Packaging: AnIntegrative Framework. Sustainability, 14/13:8045.

[8] Lozano, R., 2008, Envisioning sustainability three-dimensionally, Journal of cleaner production, 16/17:1838-1846.

[9] Heller, M. C., Selke, S. E., Keoleian, G. A., 2019, Mapping the influence of food waste in food packaging environmental performance assessments, Journal of Industrial Ecology, 23/2:480-495.

[10] Grönman, K., Soukka, R., Järvi-Kääriäinen, T., Katajajuuri, J. M., Kuisma, M., Koivupuro, H. K., ... Linnanen, L., 2013, Framework for sustainable food packaging design, Packaging Technology and Science, 26/4:187-200.

[11] Bocken, N. M., De Pauw, I., Bakker, C., Van Der Grinten, B., 2016, Product design and business model strategies for a circular economy, Journal of industrial and production engineering, 33/5:308-320.

[12] Langley, J., Turner, N., Yoxall, A., 2011, Attributes of packaging and influences on waste, Packaging technology and science, 24/3:161-175.

[13] Hanssen, O. J., Møller, H., Svanes, E., Schakenda, V., 2012, Life cycle assessment as a tool in food waste reduction and packaging optimization: packaging innovation and optimization in a lifecycle perspective, Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products, 345-367.

[14] Verghese, K., Lewis, H., Lockrey, S., Williams, H., 2015, Packaging's role in minimising food loss and waste across the supply chain, Packaging Technology and Science, 28/7:603-620.

[15] López de Dicastillo, C., Velásquez, E., Rojas, A., Guarda, A., Galotto, M. J., 2020, The use of nanoadditives within recycled polymers for food packaging: Properties, recyclability, and safety, Comprehensive Reviews in Food Science and Food Safety, 19/4:1760-1776.

[16] Ellen MacArthur Foundation, 2019, Reuse – rethinking packaging, Retrieved from https://ellenmacarthurfoundation.org/reuse-rethinking-packaging

[17] World Economic Forum, 2021, Consumers Beyond Waste – Design Guidelines for Reuse, Retrieved from https://kidv.nl/media/cop/herbruikbaar/wef consumers beyond waste community paper design guildelines sep 2021.pdf?1.2.3

[18] Steenis, N. D., van der Lans, I. A., van Herpen, E., & van Trijp, H. C., 2018, Effects of sustainable design strategies on consumer preferences for redesigned packaging. Journal of Cleaner Production, 205:854-865.

[19] Grönman, K., Soukka, R., Järvi-Kääriäinen, T., Katajajuuri, J. M., Kuisma, M., Koivupuro, H. K., ... & Linnanen, L., 2013, Framework for sustainable food packaging design. Packaging Technology and Science, 26/4:187-200.

[20] Yokokawa, N., Amasawa, E., & Hirao, M., 2021, Design assessment framework for food packaging integrating consumer preferences and environmental impact, Sustainable Production and Consumption, 27:1514-1525.

[21] Wever, R., Vogtländer, J., 2013, Eco-efficient value creation: an alternative perspective on packaging and sustainability, Packaging Technology and Science, 26/4:229-248.