Product Design of a Zero-waste Toothpaste Packaging

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Abstract — Since the development of the modern plastic industry, humanity have depended on plastic as an affordable, versatile and durable material. The convenience this material offer, however, let to a throw-away culture that account for the massive pollution nowadays. As for the toothpaste packaging, the small size, blended material and leftover toothpaste inside toothpaste tubes make recycling impossible. To overcome this mismanaged waste and unexploited recycling alternatives, Design for Environment has surged to develop environmentally compatible products and processes encompassing all life cycle phases, to reduce lifecycle impacts while preserving performance standards. Therefore, this research aims at filling the literature gap by developing a fully specified prototype of a zero-waste toothpaste packaging within the frames of the circular economy and eco-design to cope with the excessive volumes of plastic, by adopting a methodology centered on Slack et al. (2007) approach, which comprises the five pillars of product design. In this regard, a complete research on the plastic market is conducted, as well as a literature review on the circular economy, product eco-design and respective drivers and barriers. The results of the analysis enabled to selectect a concept which meets the majority of design requirements based on consumer research and propose a model where the toothpaste tube is a container that can be refilled with toothpaste. The viability of the proposed solution is then validated by conducting a life cycle assessment and a business evaluation, to perform both environmental and financial project appraisal that defines the starting point for launching the product.

Keywords: Eco-design, Circular Economy, Toothpaste Packaging, Plastic, Recycling

1. Introduction

The world is currently producing more than 300 million tons of plastic each year, predicted to double within 20 years and nearly quadruple by 2050 (MacArthur, 2017). Although cheap, versatile, lightweight, and resistant, this unique material considered the "ubiquitous workhorse material of the modern economy" (MacArthur, 2016) has faced a remarkable global shift from durable and reusable to single-use application, mainly driven by the packaging industry. The fact that most plastics are not biodegradable, coupled with their extreme durability, means that most of today's manufactured polymers will prevail in the environment for at least decades, if not centuries (Hopewell et al., 2009). Its growth has far exceeded the capacity of waste management to sustain (Hopewell et al., 2009). This short lifetime that led to a take-make-dispose culture coupled with mismanaged waste and unexploited recycling opportunities, caused the environment to be now facing a serious challenge that has to be acknowledged and addressed (Geyer et al., 2017). Plastic packaging encompasses plastics' largest application and is encountered by virtually everyone daily, which reflects in the share of the waste generation it occupies (MacArthur, 2017).

There is a significant under-exploited potential to capture greater value in plastics that could be radically improved by recycling and compounding action and innovation across the global value chain. More specifically, toothpaste tubes possess a linear business model hasn't changed since its first appearance and therefore has to be discarded once it is empty. The toothpaste industry alone produces more than 20 billion tubes every year that are usually made of plastic, aluminium, or a plastic-aluminium composite made from sheets of plastic laminate and a layer of aluminium pressed together in a film, which makes them cheap and convenient to use. The small size, blended material and leftover toothpaste inside toothpaste tubes make recycling almost impossible (Mazzoni, 2018). Other toothpaste concepts that avoid plastic have been developed by several companies that can come as a solid block, in tablets or as a powder. However, such alternatives can compromise the usability criteria when compared with the conventional toothpaste gel

To cope with this mismanaged waste and unexploited recycling alternatives, Design for Environment (DfE) has surged to develop environmentally compatible products and processes to reduce lifecycle impacts while preserving performance standards and value for money (Holdway et al., 2002), while encompassing all life cycle phases from material extraction, manufacturing, transportation, usage and end-of-life (Rose, 2000).

Starting by reviewing the state of the art on Circular Economy and Product Design, this dissertation aims to provide a fully specified prototype of a zero-waste toothpaste packaging within the frames of the Circular Economy and Eco-design.

2. STATE OF THE ART

2.1. Circular Economy

Four principles of the CE were outlined by MacArthur (2016) as points of action to eradicate negligent resource depletion and strengthen existing material value in industry (1) Optimise the use of resources and energy throughout lifecycles, (2) Maintain products and components in use for longer, (3) Materials cycle through the system as many times as possible through cascaded uses (4) Utilise pure materials for improving quality of post-life use. It is within this context that the circular economy acts as a pathway to product sustainability. Therefore, it becomes vital for product manufacturers to consider business models and product design in the development of truly circular industrial systems. While the first focus on the way products are commercialized and consumed, product design is mostly concerned in potentializing materials value at any point in their lifecycles (Franco, 2019).

2.2. Product Design

The design activity is itself a process that requires a number of steps on the path followed by an innovation from a concept to a fully specified state, moving from the (1) concept generation stage to a (2) screening stage, (3) a preliminary design stage that produces a design to be (4) evaluated and improved, before reaching the (5) prototype and final design (Slack et al., 2007). Concept generation transforms an into a concept which captures the nature of the product and provides an overall specification for its design. Screening the concept takes place afterwards to ensure that the product is a logical integration to the company's portfolio. The Quality Function Deployment (QFD) is used during the problem definition phase to transfer customer requirements (CR) into specification before manufacturing (Kuo et al., 2001). Having generated an acceptable, feasible and viable product concept, the next stage is to create a preliminary design, turning it into a manufacturable product (Slack et al., 2007). In this stage all the product's component parts and the way they articulate are identified. The resulting design is then subject to an evaluation stage, which involves re-examining the design (Slack et al., 2007). Similarly, Deloitte (2019) prosed the UNLEASH Innovation Process that is meant to advance ideas and solutions through the innovation process, ultimately leading to the implementation of solutions that can help address the Sustainable Development Goals (SDGs). This process comprises five phases that are closely linked with the design stages presented above. As also introduced in Unleash by Deloitte (2019), the user should be at the centre of every step of the innovation process so that the solutions are grounded in a deep understanding of you're the user's wants and needs. Therefore, in this stage a user profile is developed based on the data collected from a survey performed to potential customers of the product. Surveys are very useful to collect standardized information instantly from a wide audience, irrespective of their geographical location, in a cost-effective way. This tool enables the gathering and comparison of information across different groups of stakeholders on an array of issues surrounding their behaviour, thoughts, and feelings (Buchanan and Hvizdak, 2009).

2.3. Design for Environment

DfE or eco-design aspire to develop environmentally compatible products and processes (Ramani *et al.*, 2010) to reduce lifecycle impacts while preserving performance standards and value for money, considering such issues as business opportunities (Holdway *et al*., 2002). DfE, an inherent constituent of the DfX paradigm, encompasses all life cycle phases from material extraction, manufacturing, transportation, usage and end-of-life (Rose, 2000). The importance of the early stages of the innovation process seems to be a consistent theme within the engineering design perspective. The product design stage of the life cycle has the most significant environmental impacts as it was estimated that 80% of the environmental burdens are locked in during this stage, which will establish the pollutants and wastes a product will discharge during its lifetime, the energy it will consume, and how easily its components will be reutilized in consequent uses and manufacturing cycles (Franco, 2019). Therefore, the earlier environmental issues are considered during development, the higher is the chance of reducing both their associated impacts and costs, as it is also acknowledged that 70% of the final product costs are determined in the design process (Birch et al., 2012).

The use of LCA tools as key to assist designers on the product's life costs assessment and consequently manage material choices for ecological optimisation is systematically promoted by authors (De los Rios and Charnley, 2017). LCA is a quantitative tool specifically defined by related ISO 14040 and 14044 standards (ISO, 2006a,b) as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle, and from the environment assessment tools available for evaluating the environmental profile of a product or process, LCA has arisen as the most objective one (Ramani et al., 2010).

This chapter has revealed a main gap that should be addressed. Currently there are no solutions on the market that address a zero-waste packaging concept combined with a reuse system for toothpaste that, therefore, avoids it to be thrown once it is empty. In this regard, several product design methods were analysed (Slack et al. (2007), Ulrich and Eppinger (2012), Deloitte (2019)) that aid in develop an integrated product design strategy to address the gap identified.

3. Methodology

To pursue the product design activity, an iteration process to accomplish the current project was defined based on the Literature Review. The methodology to be followed throughout the dissertation will be based on the design process proposed by Slack *et al.* (2007) which was further extended to a multi-methodology approach to integrate a more User Centered Design (UCD) perspective. This thesis methodology is comprised by five major phases, each with its adjacent septs. A schematic representation in provided in Figure 1.

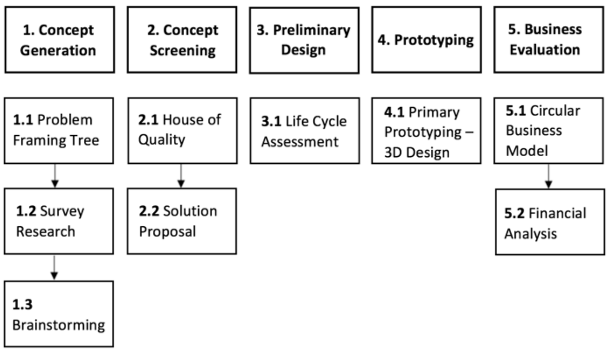

Figure 1 - Master dissertation methodology approach

The Concept Generation stage transforms an idea into a concept, capturing the nature and overall design specifications of the product. In step 1.1 this process will resort to the Problem Framing Tree tool that is responsible to ensure that there is a specific problem framing. As suggested by Deloitte (2019) on step 1.2 a survey research should be performed to identify and structure customer requirements. The survey was developed in electronic format, using the *Google Forms* platform. An introductory text was used to explain the study and its context, and the survey structure. It was then divided into three sections: I - Consumer Insights; II - Product Information; III - Consumer data. The first part is aimed at understanding consumer information regarding the environmental problem that toothpaste represents, how willing they are to change their current toothpaste method and what reasons would prevent them from doing so. The second part aims to define product requirements, first understanding consumer thoughts on zero waste toothpaste solutions currently on the market by rating their preference for these solutions, and secondly by allowing them to rate a list of packaging criteria on a scale of 1 to 5. The last part focuses on collecting demographic data from the group of participants.

On the Concept Screening stage, the proposed concepts are evaluated. A commonly used technique for concept selection is the House of Quality (HoQ) as it is used to translate customer needs into technical requirements, starting from the Voice of the Customer (VoC), providing inter-functional product planning mapping to link engineering attributes to customer desires, which are ranked in importance. The HoQ utilizes a weighted-sum multi-objective decision criterion, entailing technical test measures (benchmarking) analysis, technical importance rankings and estimates of technical difficulty to enable a decision maker to set performance targets for a designed artifact (Hoyle and Chen, 2007).

During the Preliminary Design stage, the product's component parts and the way they articulate are identified, which must be aligned with the requirements for the user and producer. Therefore, in step 3.1 a Life Cycle Assessment (LCA) allows to assess and identify key materials and processes within the products' life cycles that are likely to pose the greatest impacts, including resource demand and human health impacts. The LCA process is a systematic standardized method (ISO, 2006a, b) defined in four phases:

1. Goal definition and scoping − A clear definition of the system boundaries that comprises which methods are going to be considered (impact categories), the life cycle, the physical, geographical and temporal boundaries, data limitations and quality of the data.

2. Life cycle inventory (LCI) analysis − Create an inventory of flows from and to nature for a product system.

3. Life cycle impact assessment (LCIA) − Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

4. Interpretation − Evaluate the results of the LCI and LCIA to select the preferred product, process or service. This phase should be reinforced with facts and calculations to support the results, such as uncertainty analysis, sensitivity analysis and contribution analysis.

The Prototyping stage provides a model explaining the actual plans for the final product, by developing a primary form of the product as a 3D design. Here the product is broken down into its components, explaining the features and functionalities of each one in a perspective of "works like" and "looks like" prototype.

After proving environmental viability, the last stage will provide a Business Evaluation in two steps. Firstly, a financial analysis that will evaluate the viability, stability, and profitability of the project, and secondly the development of a business model to outline the plan for making a profit, according to the business model canvas developed by Osterwalder and Pigneur (2010). Below are the steps suggested by Sharma (2014) that can be taken to complete the entire process of the financial justification for a new launch:

1. Data Collection − size of the market, demographics, Compounded Average Growth Rate (CAGR) of the market, and market location and scope (global versus regional).

2. Estimate incremental investment needed as well as the Cost of Goods Sold (COGS) − If the new product requires some initial investment such as additional R&D activity or developmental work, an advertising campaign, hiring a salesperson or a sales team, preparing marketing

brochures, etc., then an estimated fixed cost for these tasks need to be prepared.

3. Complete a breakeven analysis and estimate the fraction of market size required to get breakeven revenue − A breakeven (BE) analysis is required to understand how many units must be sold in this new segment to recover the incremental fixed cost investment.

4. Create a Discounted Cash Flow (DCF) model to calculate Internal Rate of Return (IRR) and Net Present Value (NPV) for the launch − A DCF model can be created using market CAGR as the sales growth rate assumption. If the NPV is positive over a 5- or 10-year period and the IRR is greater than the discount rate, then it is fair to say that there is reasonable financial justification to move forward with the project.

4. Results

4.1. Concept Generation

It is particularly important to study the packaging of oral care products from the users' point of view. The results presented consider the data collected from 91 completed surveys, which were then exported to Excel and analysed. The sampling used is a non-probability convenience sampling, because of its speed, cost-effectiveness, and ease of availability of the sample. The second section of the survey was meant to characterize the consumers knowledge, in order to understand how aware and concerned they are. The answers to the first question "Are you aware that the majority of toothpaste tubes contain 11 layers of plastics, polymers and resins and therefore are not recyclable?" reveal that 92% of respondents are not aware of the environmental concerns circling toothpaste packaging, namely its technical challenge to be recycled due to the combination of plastic, aluminum and resins in its composition, which means that the major share of these materials is discarded by conventional means. Regarding this serious drawback of toothpastes, to the question "Knowing this info, is it a problem for you?" the vast majority (96.7%) say they consider this a concern, which reveals a group that is sensitive to these issues and that may be willing to change their habits. However, much remain to be done as the third question "Are you familiar with any environmentally conscious toothpaste alternatives in the market?" revealed that 89% of them are unaware of substitute alternatives in the toothpaste market. This means that these sustainable options are not reaching the masses, even though there is a willingness on behalf of the consumer to adopt them. In order to understand if price would be a barrier to purchase, the consumer group was asked if they would be eager to afford a more expensive sustainable option. About half (49%) said they would be willing to pay extra, while a similar proportion (46%) did not express a positive or negative response, certainly because their choice can be conditioned by several factors to be taken into account at the time of the decision. Only 4% declined to pay more. The last question on this section intended to understand which factors would prevent customers from adopting sustainable toothpaste solutions when compared to the current toothpaste option they are currently using (with the exception of 3 respondents who said they already used eco-toothpastes). The results are shown in Figure 2.

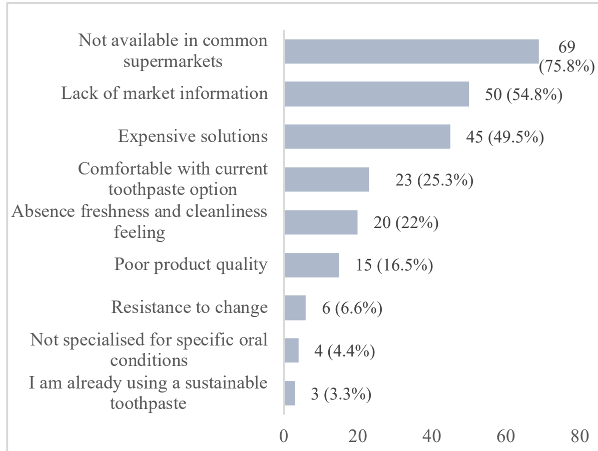

Figure 2 - Reasons that may prevent respondents from adopting sustainable toothpaste solutions when compared to the current toothpaste option they are using

About half refer that that the price to be paid for such solutions is a factor that can condition the purchase, since sustainable products are generally more expensive. Approximately 55% indicate the lack of information and awareness on these solutions as being one of the obstacles. Again, consumers cannot purchase products they are not aware of. It is important to take into account that that the solution is not always more marketing, because the problem may lie with where the product is being marketed and what marketing vehicles are being used, *i.e.* to assess the key demographics of the target market and research where these marketing efforts are most likely to reach them. Another aspect that correlates with the one just mentioned, is the perceived value of the product. About a 17% of the respondents pointed 'Poor product quality', reflecting (1) actual lack of quality of some of these products or (2) consumers inability to recognize the benefits to create perceived value. Regarding the second aspect, if a customer cannot see the value, they will simply pass the product by. That perceived value comes in actually showing people using the product through advertisements, demonstrations, or other means. Regarding the toothpaste experience, 36% point the lack of freshness a cleanliness feeling after using it and 4% add that they need specialised solutions for specific oral conditions, such as sensitive gums or teeth, which are not found in the eco-toothpastes portfolio available. A total of 23 respondents reported to be comfortable with their current toothpaste option and therefore would not be willing to change. Similarly, 6.6% reported to be resistant to change. Innovation resistance is a normal, instinctive response of consumers, as naturally it may create a high degree of change in their day-to-day existence and disrupt their established routines. Finally, only 4 reported to be already adopting this type of sustainable alternatives.

Finally, the last section aims to extract information regarding consumers' views on sustainable toothpaste alternatives in order to understand their preferences and thus shape the product developed according to them. Five eco-toothpaste solutions have been presented – Edible Pod, Toothpaste Tabs, Powder Toothpaste, Solid Toothpaste and Glass Jar Cream Toothpaste. The first question revealed that at least one person had already tried each of the different types of toothpaste with the exception of edible pods. This makes sense as edible pods were developed by the American start-up *Poppits* (Poppits, 2021) who are not available just yet but launching Spring 2021. The results to this question exhibited in Figure 3 show that the powder and solid toothpaste formats are the ones that generate the most 'not willing to try' answers. Nevertheless, a large portion of them is open to experiment these products, which reveals the opportunity to explore both this market and solutions that can incorporate some of these concepts.

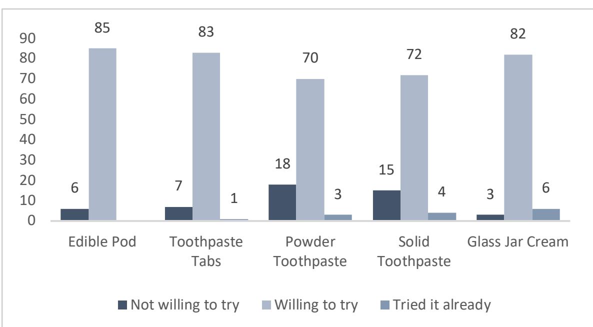

Figure 3 - Willingness to try zero waste toothpaste solutions

On the last question respondents were asked to build a ranking in order of preference among the solutions presented, in terms of how comfortable they would be in replacing their current toothpaste option for one of these. A scoring scale 1-5 has been assigned according to the preferred position, from a weight of 5 points for the most favourite option to a weight of 1 point for the least favourite option. The results are shown in Table 1.

The results reveal a preference for gel-shaped toothpaste formats, with the highest score attributed to edible pods, followed by the glass jar. Although the way dent tabs are used is exactly the same as the edible pods, the fact of being solid can awaken in users the sensations aforementioned for solid pastes, which guarantees them a place in the middle of the ranking. The least favourite formats are the solid and powder toothpastes with the 4th and last positions, respectively.

Table 1 - Results from the scoring attributed to each toothpaste option

		Edible Pod		Toothpaste Tabs		Toothpaste Powder		Solid Toothpaste		Glass Jar Cream	
	Points	N	Score	N	Score	N	Score	N	Score	N	Score
1st option	5	41	205	7	35	0	0	10	50	33	165
2nd option	4	26	104	17	68	11	44	5	20	32	128
3rd option	3	12	36	46	138	9	27	6	18	18	54
4th option	2	6	12	18	36	28	56	34	68	5	10
5th option	1	6	6	3	3	43	43	36	36	3	3
	Total	91	363	91	280	91	170	91	192	91	360

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All in all, the results reveal a general lack of knowledge and awareness regarding the serious recycling drawback of toothpaste packaging, but the public is sensitive about it and open to adopt solutions that limit this problem. This is, therefore, a market with a high potential, but among the biggest obstacles to its growth are the lack of information, perceived value, the price to pay and the unavailability of these toothpaste items in the common customer's channels of purchase. When it comes to developing a new product, it is perceptible that the public ideally chooses a traditional gel paste, preferably one that brings them the greatest comfort of use and the least deviation from the oral hygiene routine they have always had. This last point is closely related to resistance to change and the comfort that the traditional toothpaste option provides, which are factors also mentioned by the participants and which should also be taken into consideration during the next development phases.

4.2. Concept Screening

This stage comprehends the evaluation of the concepts that result from the research performed during the Concept Generation stage, which will allow to narrow down the number of ideas into a single concept. Customer Attributes (CA's) are defined as the physical or abstract characteristics of a product. Based on the inputs for the system design provided during in the previous chapter, the HoQ was used as the analysis tool for the several attributes extracted. The ratings for the weights are between 1 and 5, with 5 being the most important rating The following CA's presented in Table 2 were derived.

Table 2 - Customer demands with associated weights

CA's	Weight
Hygienic: Keep product well preserved and fresh	5
Minimum waste: Almost all the toothpaste comes out	5
Easy to dispense: It does not require too much effort to use.	5
Retains shape: the container retains its original shape	3
Reasonable cost: It should cost about the same as present containers	4
Attractive container: Look good either on the store shelf and also on the counter in the bathroom	2
Leak proof: Resistant to leaks	5
Squeezable: People want to squeeze the container	4
Pleasing taste: Enjoyable toothpaste flavour	5
Environmentally friendly: Claim minimal, or no harm upon ecosystems or the environment	4
Resolve dental problems: Clinically proven toothpaste for people with dental issues	3
Portability: The ability to be easily carried or moved	4
Possibility of Controlled Dosage: The user decides the amount of toothpaste to be applied	5

The Technical Requirements are placed on the top of the house. These must be measurable and within the control of the manufacturer. The brainstorming with a product designer was used to develop the technical requirements, along with various Internet sources for references existing standards. Eleven technical requirements were developed (1) Malleable material, (2) Hermetic, (3) Squeezable top and bottom, (4) Design for Logistics, (5) Ergonomic convenience, (6) Robustness, (7) Reusability, (8) Washability, (9) The toothpaste itself is chosen by the consumer, so he can opt to use a mass-market option that he might prefer due to its texture, taste and therapeutic features (10) Different colours and (11) Limited size.

Once the CAs and the TRs were developed, a relationship matrix was constructed. The matrix defines the correlations between both as weak, moderate, or strong using a standard 9-3-1 scale. This matrix identifies the requirements that satisfy most customer demands and determines the appropriate investment of resources for each. The TRs that addressed the most customer consequences should be dealt into the design process to ensure a customer approved product.

The relative importance of each technical requirement was calculated by multiplying the value assigned to its relationship with a specific consequence (9, 3, or 1) multiplied by the importance of that consequence; the values of all consequences were then added to yield the final weight. These weights were placed in a row at the bottom of the HoQ. The full overall HoQ for the new toothpaste container product is shown in Figure 4 below.

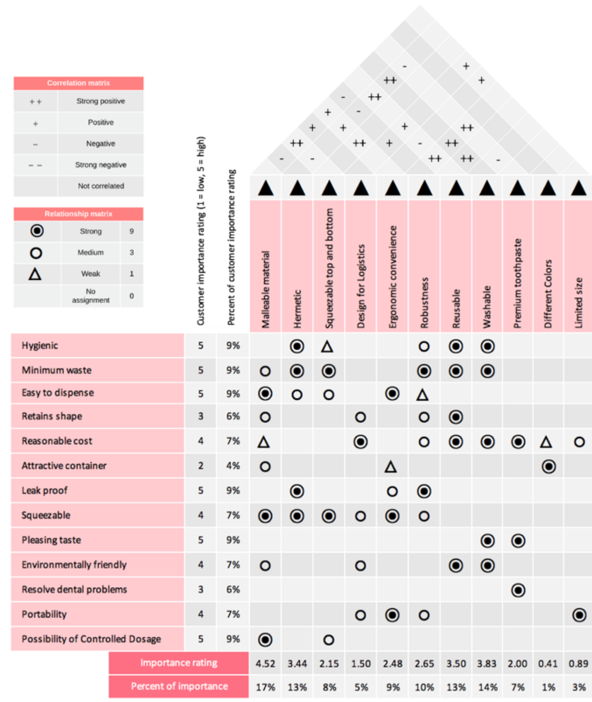

Figure 4 - House of Quality for the new toothpaste design

From the HoQ, the most important quality characteristics worth to be considered for this product are (1) Malleable material with a weight of 17%, (2) Washable with a weight of 14%, followed by (3) Hermetic and (4) Reusable, both weighting 13%. The HoQ realizes the need for a container composed of a malleable and flexible material, a characteristic that will allow it to have a better performance in the other technical requirements pointed. Such material is required to be robust and able to be reused through multiple washes, since hygiene is an attribute valued by the consumer especially given the product we are dealing with, that is required to be well preserved and fresh. By being malleable it will also allow the toothpaste squeeze and therefore the possibility to control the dosage applied for each use. The ability to choose the toothpaste that is used within the container is also valued by users. Many consumers already have their toothpaste brands of choice, whether for the taste, the feeling of freshness it provides or even for being suited to particular medical conditions.

The research conducted revealed that the majority of customers are willing to switch to a sustainable alternative, however they are reluctant on abandoning a familiar format to which they are already accustomed, especially regarding the type of paste, which should preferably be a gel. Hence the selected concept which meets the majority of design requirements is based on the squeeze mechanism. The solution is based on a Circular Business Model with a hybrid model where the toothpaste tube is a container that can be refilled and therefore reused with toothpaste bought separately.

The product will now be broken down into its components, explaining the features and functionalities of each one in a perspective of “works like” and “looks like” prototype. The Reusable toothpaste tube should have plastic properties, since it has to be extremely malleable and robust, allowing a long-life cycle through a great number of reuses and washes, while lightweight for maximized logistics efficiency. Silicone has become very popular as an alternative to plastic over the years. This high-end material is safe, nontoxic, non-allergenic and non-reactive, eco-friendly, easy to shape and manufacture, extremely durable and resistant, possessing a long lifespan up to 30 years (David Suzuki Foundation, 2021). Taking this in consideration, the tube is made of soft and squeezable BPA free food grade silicone that only dispense its contents when the silicone body is pressed. Each container includes a flip cap and a dispenser valve to protect from leaks, spills or drops. This prototype will have a size of 80 ml, which is an easy to carry and travel size that consumers are already used to have in their homes. The silicone bottle concept has an additional feature: a zip lock top. This feature will allow an easy refill process for the toothpaste, which is inserted through the top opening. On the other hands, when closed, the zip will ensure that the toothpaste does not escape. The Cap is made of polypropylene (PP), which is known for good impact strength, durability, cost effectiveness, thermal resistance, and pliability. PP is 100% recyclable and considered safe for reuse (Omnexus, 2020), and one of its greatest benefits is that it can be employed in the manufacture of living hinges as it does not break when repeatedly bent. The lid has a set of spikes that ensure that when the refill is placed inside the container it is perforated to release the toothpaste. The Toothpaste Refills hold the same amount of toothpaste of a regular tube of 75 ml, packaged in water-soluble and biodegradable film. This edible food-grade film is made of Polyvinyl Alcohol (PVOH), which is safe, GRAS-certified by the FDA, environmentally friendly and is used in other nutrition supplements and food products. It dissolves completely in water and naturally breaks down into water and carbon dioxide. It does not persist in the environment, contaminate the recycling stream nor contribute to micro-plastic pollution (Poppits, 2021). These refills are relatively water and impact sensitive, which invalidates the use of solely paperboard to carry them. The best solution that combines the desired unique properties of keeping the liquids in but the microbes out, and a strong but lightweight container are Tetra Pak food cartons. These cartons are mostly made (about 75%) from wood. Aseptic cartons then use a layer of aluminium (5% of aluminium) to preserve the product and layers of plastic (20% of polyethylene) to seal the container. Furthermore, Tetra Pak cartons are easy to transport and fully recyclable (Tetra Pak, 2021). A comparative LCA led by the german institute IFEU, compared the environmental footprint of cartons, glass jars, tin cans and retortable pouches by measuring its performance in eight categories. Cartons came ahead in all but one category (use of nature, because of their use of trees). The study showed that cartons’ total primary energy consumption was the lowest of all four systems. Thus, it is concluded that this type of carton is the material that makes more sense as packaging for the refills, that is proposed to come in packs of two, saving both on packaging material and transport, reducing the number of travels to the points-of-sale to purchase more units.

4.3. Preliminary Design and Prototyping

This section summarizes steps 3 and 4 of the methodology. The primary goal of this study is to determine the environmental burdens of adopting the new toothpaste package developed relative to the mass-market alternative packaging, using the LCA methodology.

The different toothpaste packaging systems at issue are (1) the food grade silicone bottle with PP cap, (2) the standard laminate tube and (3) the HDPE mass-market variant for toothpaste container, which for the analysis will be called (1) New System, (2) Traditional System 1 and (3) Traditional System 2, respectively. The three will package 75ml of toothpaste. In the theoretical substitution analysis, the impacts of current amounts of laminate and HDPE packaging are compared to a scenario in which these containers are substituted by the silicone as an alternative material that extends its lifecycle. All of the plastic resins investigated in this study are modelled to be sourced from fossil fuels (i.e., natural gas and petroleum).

From ReCiPe Endpoint (H), the impact categories addressed in the analysis include Agricultural land occupation, Climate change Ecosystems, Climate change Human Health, Fossil depletion, Freshwater ecotoxicity, Freshwater eutrophication, Human toxicity, Ionising radiation, Marine ecotoxicity, Metal depletion, Natural land transformation, Ozone depletion, Particulate matter formation, Photochemical oxidant formation, Terrestrial acidification, Terrestrial ecotoxicity, Urban land occupation. The functional unit (FU) is intended as a reference unit for which the inventory data are normalized (ISO, 2006a, b). The function examined in this LCA study is the packaging of toothpaste for retail. According to the manufacturers, the food grade silicone container will have an estimated lifespan of 10 years during which a warranty is offered, while the 75ml tube has an average lifespan of few months. The primary packages examined are technically equivalent regarding the mechanical protection of the packaged toothpaste during transport, the storage at the point-of-sale and the use phase. Considering this, and since the intention is to compare the environmental impact generated by toothpaste packaging with different lifecycles, the functional unit is the number of brushes over a 10-year period. Assuming brushing two times a day, this represents 7300 washes during the time boundary considered. The recommended a pea-size amount of toothpaste will allow a tube to last approximately 188 brushes, which brushing twice a day corresponds to 3 months of use. Given this need, Figure 5 illustrates the use of packaging over the 10-year period. Both Traditional Systems 1 and 2 require the same number of packages, which corresponds to 40 units. The New System, on the other hand, requires only one silicone squeeze tube, accompanied by 40 refills present in 20 packs.

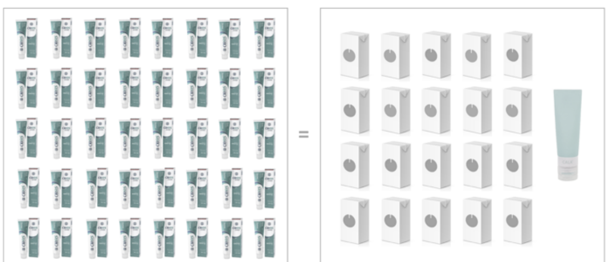

Figure 5 - Packaging requirements for the functional unit during the stipulated 10-year time frame

This study is a 'cradle-to-grave' LCA, in which the processes considered for each packaging system are the extraction of the packaging raw material, the resin production, the container formation (taking into account the different processing phases) and, finally, the end-of-life of packaging materials (tubes and secondary packaging), also including the closed loop recycling through the recycling of carton and plastic materials during the manufacturing phases. The analysis carried out will comprehend the container alone, and therefore does not take into account the toothpaste inside of it, the loss during the filling phase or use of the toothpaste. In order to get the comprehensive results, the transportation was included within this system's boundaries, especially because of the long distances over which the raw materials for the composite packages needed to be transported. The transport distances of raw materials in this study were calculated based on the average distances between each supplier and the manufacturing plants estimated by the Ecoinvent database for the European (RER), Switzerland (CH), rest of the world (RoW) or global (GLO) regions. Regarding the transportation of the products from the producers to the retailers it was assumed a distance of 581 km (Eurostat, 2019), which is the average road freight distance within the European context. Finally, the materials end-of-life is also assessed, considering the European scenario as the reference, in terms of the percentage of raw materials recycled, incinerated and disposed to landfill.

The end-point results are finally aggregated to achieve the single-score LCA impact results which are presented in Figure 6. The Traditional System 1 and Traditional System 2 carry the total single-score (SS) impact of 671 mPt and 496 mPt, respective, while the New System plants carries the total single-score impact of 134 mPt. The SS impacts indubitably demonstrate the New System as the most environment-friendly toothpaste container solution, representing less than a third of the impact generated by Traditional System 2 and five times less impact than the Traditional System 1. It is worth mentioning here that 1-point (1Pt) LCA impact indicates the impact caused by an average global citizen over the time period of 1 year.

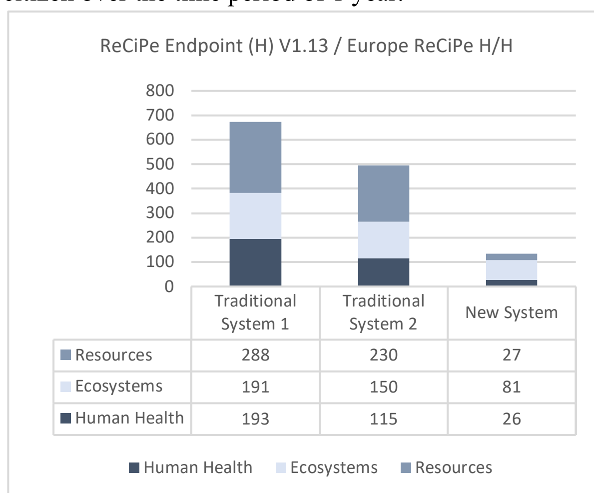

Figure 6 - Endpoint-based SS analysis using the ReCiPe Endpoint (H) V1.13 / Europe ReCiPe H/H

The New System improves all the three impact categories, but of special note is the relief it represents in the *Resources* category, which is the one whose weight is greater in the other systems. While *Resource*s impacts almost 50% of the SS of both Traditional Systems (43% for Traditional System 1 and 47% for Traditional System 2), it impacts only 20% in the New System. The *Ecosystems* category in the New System is the one which weighs the most, roughly 60% of its SS, precisely because of the constitution of its FU.

Now that its environmental viability has been proven, the primary prototype of the proposed solution is presented. As already detailed in the solution proposal, the selected concept which meets the majority of design requirements is based on the squeeze mechanism. The aim is that this solution represents for the consumers the minimum disruption and effort of getting used to it, as it works in the same way as the standard tubes. This represents a great advantage over other competitors as it can be more easily adopted by a wider audience, as it provides an intuitive use. The described system is shown in Figure 7.

Figure 7 - Toothpaste design proposal

5.4. Business Evaluation

Between 2021-2026 the global oral care market is expected to witness a healthy growth at a CAGR of 5.2%, expecting to attain a value of USD 45 billion in 2026. The growing awareness about oral hygiene and a higher penetration into emerging economies is likely to drive the industry. In Europe this market was worth nearly USD 8.78 billion in 2020 and is expected to attain USD 10.66 billion in 2026, growing at a CAGR of 3.3 % in the forecast period of 2021-2026.

The costs of launching the project are estimated and described in Table 3.

Table 3 - Project cost estimates

R&D development cost	€	**25 000**
SG&A (Advertising, product launch)	€	40 000
Capital Equipment expense (Amortized over 5y)	€	30 000
Sales team (2 collaborators)	€	80 000
Intellectual property (Amortized over 5 y)	€	20 000
Total Year 1 Project Cost	**€**	**195 000**

Next step is to determine the Cost of Goods Sold (COGS) for this new product introduction. It was assumed that the Net Selling Price (NSP) per container is 4.99€ and the Variable Manufacturing Cost (VMC) is 1.5€ /unit, which accounts for 30% of the selling price. It was also considered a freight and packaging cost of 0.05€/unit, so the total Variable Cost (VC) is 1.55€/unit. Therefore, the value of the Contribution Margin (CM), which is the difference in the NSP and VC, is 3.44€/unit. It can be assumed that at least BE units will be sold in the first year. It was found a positive NPV of 550 392€, assuming the market CAGR of 3.3% as the sales growth rate and 12% discount rate over a 5-year period. The same cash flows led to an IRR of 99.5%, which is clearly greater than the hurdle rate. It is then concluded that there is a great potential for growth in the market, which is also complemented by a positive NPV and an IRR that exceeds by far the minimum attractive rate of return of 12%. The higher this IRR, the more desirable the investment is to undertake, and therefore these results demonstrate that there is reasonable financial justification to move forward with the project.

Table 4 - Breakeven Analysis

BE Units		**56 686**
BE Value	€	282 683
Total Market Size (B €)	€	8.78
Market Share needed to breakeven		**0.003 %**

A sustainable business seeks not only economic value but also social and environmental values for a much broader group of stakeholders. A sustainable business model can be defined as one that generates competitive advantage thanks to greater customer value while contributing to sustainable development of the organization and society. The circular business model canvas is extended and adjusted to the circular economy version of the business model canvas developed by Osterwalder and Pigneur (2010). This model begins with the quest to sell a circular economy solution for the toothpaste packaging, based on a reuse system that is sustained through a subscription program. This will allow the customer to comfortably receive the toothpaste refills at home as soon as he needs it, making it easy to keep brushing uninterruptedly. At present, the young consumers are shaping an environmental movement and becoming more and more aware of how their choices and consumer habits affect the planet. Therefore, the main targeted segments are (1) Young adults who are looking for an affordable soluble solution with great sustainable features and (2) Urban and eco-friendly adults and middle aged who want to use an ecologically benign product associated with its commodity. The product will mainly be sold via virtual channels, and communicated with customers virtually, however it will be available in common supermarkets as well as its easy accessibility in these surfaces has proven to be an important factor when buying a toothpaste solution. The availability of raw materials, technologies and specialists is ensured by the suppliers and distributers. Out of the group of suppliers represented, the most critical are the food-grade-membrane partners, as it is a specific technology and does not yet have a large-scale market presence. This partnership can be extended to include co-operation with global toothpaste manufacturers such as Colgate, which preserves the membrane technology yet containing a market leading toothpaste, with its experience and quality to develop a competitive strategy to face other competitors, especially in the emergent countries.

The main activities are in the first phase very focused on R&D, where the main resources will be the development teams for both product design and online presence, as well as patent protection and certificates. In a second phase the main activities will focus on supply chain management, from production in the local factory and distribution to supermarkets or to customers' homes. Here the main resources are raw materials from recycled streams that are transformed in production plans. In addition, the existing customers of the toothpaste partner become key resources, as they would also buy the container, which becomes a complementary product, as both goods cannot be used without each other. Finally, Marketing has a critical role in changing consumer patterns by informing, educating, and channelling needs of its current and potential customers towards the sustainable development. This availability of information and spread of awareness will facilitate the triggering of consumption opportunities.

Conclusion and Future Work

The results obtained that the new solution proposed has the potential to replace the current traditional toothpaste systems, by demonstrating a very significant reduction in the environmental impact generated. This design stands on the ease of reuse, disassembly and recycling, rather than the continuous extraction of resources on a take-make-dispose system. However, it is worth noting that the simultaneous satisfaction of all requirements constitutes a major challenge in the design process, as there may be conflicts emerging from the interactions between several features. The main limitation of this research was the inability to produce a physical prototype that could even be tested by a focus group, which is pointed as the future work.

In conclusion, this dissertation has contributed to filling out the literature gap on the zero-waste toothpaste packaging by adopting the methodology proposed by Slack et al. (2007). Additionally, this research has contributed to a sustainable solution in reducing the excessive volumes of plastic waste which are threatening life as we know on planet Earth.

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