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DESIGN FOR LONGEVITY - A FRAMEWORK TO SUPPORT THE DESIGNING OF A PRODUCT'S OPTIMAL LIFETIME

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ABSTRACT

Extending the lifespan of products and parts is seen as a solution in the transition towards a circular economy. There are many proposed design approaches argued to facilitate this. However, extending the lifespan of products and parts is not always desirable, and product developers should instead strive to design for a specific longevity; the product's optimal lifetime. The latter in turn depends on many various contextual factors, and this paper has identified the three main contextual factors as; the user, the business, and the resource efficiency. Considering these three appropriately can help product developers to define their product's optimal lifetime. Altogether, these components promote the mindset of Design for Longevity. Specifically, as extracted from this paper: "Design for Longevity aims at designing products with an optimal lifetime, where optimal means taking the user, the business and the resource efficiency perspectives into account when designing the life of a product". A Design for Longevity framework is proposed and evaluated in this paper, and it is concluded that the proposed Design for Longevity framework can support product developers to implement the Design for Longevity mindset.

Keywords: Circular economy, Design for X (DfX), Optimal product lifetime, Design for Longevity, Sustainability

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1 INTRODUCTION

Circular economy is a topic that has gained a growing interest both in academia and industry in recent years. Questions such as how companies can contribute in the shift from a linear economy to a circular economy have been discussed in many different ways. One framework that has been developed is *The 9R Framework* by Potting et al. (2017), illustrated and explained in Figure 1, left. Product lifetime extension is illustrated as a solution in the transition towards a circular economy in this framework. However, instead of striving towards pure product life extension, we would like to argue that product developers should strive towards a specific product longevity, such as an optimal one. Optimal product longevity, also synonymous with optimal product lifetime, is something that is and has been troublesome to define (Van Nes & Cramer, 2005), since it depends on many different factors; product, industry, business model, users, only to mention a few. However, this is a topic that remains of interest, and we believe that this can be achieved if product developers can actively consider the key aspects and thus design for this optimal longevity.

This paper is part of a larger study (Carlsson & Mallalieu, 2020). The overall goal in this paper is to develop a framework that helps product developers to **Design for Longevity**, given any *durable good* (Wikipedia, 2021) within the consumer industry. More specifically, this paper aims to define Design for Longevity, but also develop tools that help practitioners to realize it.

2 RESEARCH APPROACH

This study was performed at a technical university in Sweden where the research is closely connected to the durable goods and consumer industry. The study was also in close collaboration with professionals from the automotive industry. The study was divided into three steps.

The purpose of the **first step** was to gain knowledge and identify a research gap related to the topic of product longevity. This was done by conducting an exploratory literature review, which began with identifying a number of relevant articles within the topic of circular economy and resource efficiency, as these topics relate to product longevity (Tillman et al., 2019). Wohlin's (2014) snowballing method was applied on the articles, in order to find more relevant articles to review. A snowballing method was deemed as suitable since the review was of a more exploratory approach, where several aspects and prior views were to result in the definition of Design for Longevity. The literature was collected using Google Scholar, where keywords such as "circular economy", "circular design" and "Design for X" were used. The selected literature consisted of 36 articles, chapters from two books, and lecture material from three university courses within Circular Economy, Product Development Theory, and Product Service Systems. The selected material was read, discussed, and summarized. Further inclusion of the material was based on three things; the main points of the literature, the relevance in regard to product longevity, and the quality of each article.

The purpose of the **second step** was to develop a framework that meets the overall goal, which is a framework that helps companies to Design for Longevity, given any durable good within the consumer industry. Rossia et al. (2016) argue that developed tools and methods aiming towards product design usually have a limited usability within industry. Several requirements focusing on usability were therefore formulated and continuously used in the **second step** as well as the **third step** in order to address this. These requirements are formulated below, derived from Rossia et al. (2016) and Almefelt (2005).

- How **understandable** the framework is.
- How **applicable** the framework is.
- How **extensive** the framework is to implement.
- How important **experience** is when implementing the framework.
- How the frameworks **visual design** is perceived.
- How **useful** the framework is in determining the optimal product lifetime.
- How well the framework **supports** in identifying potential design changes.

Several initial ideas on different elements to be included in the framework were generated from internal brainstorming sessions (Chauncey, 2013). These ideas were tested on example cases, including passenger vehicles, coffee brewers, and toys. The results from this were evaluated based on the formulated criteria. This procedure was done in several iterations to improve the framework. In order to find further improvements, the generated ideas were also discussed and evaluated by conducting informal interviews with professionals working in a research environment. More specifically, these included; two professors within systems design engineering, one researcher and one associate professor within human factors engineering, and one professor within materials science.

The purpose of the **third step** was to present, test, and evaluate the framework in industry for two main reasons; verify its acceptance, and identify further improvements. This was done by conducting eight semi-structured interviews (McIntosh & Morse, 2015) with professionals working with product development from two large actors within the automotive industry. More specifically, these included; one from CAE, four from middle management, and three from product design. The automotive industry was deemed as a good study object due to the nature of passenger vehicles, since they are considered to be durable goods as well as products with many conflicting needs. The interviews took between one and two hours and were performed online as a precaution due to the ongoing pandemic. The interviews consisted of three parts; present the framework and its elements, apply it on a hypothetical example case (passenger vehicle), and collect the interviewee's opinions regarding the framework and its use. The last part was done using a questionnaire that consisted of 17 questions aiming at the predefined criteria. The questions were formulated using a Likert scale in order to obtain the interviewee's attitude towards the framework (Albaum, 1997), collecting both qualitative and quantitative data.

3 LITERATURE REVIEW

Almefelt (2020) discusses product longevity as a concept with two dimensions, *desired* service life, and *actual* or real service life. Products can be designed in such a way that these two dimensions either match or not, illustrated in Figure 1, right. In this illustration it is assumed that appliances do not match their expectations on service life – based on user preferences. Furthermore, the fishing net's lifetime, now seemingly a ghost net, is also assumed to exceed the desired service life – from an environmental point of view. Supporting this, through an empirical study, Cooper (2004) more concretely demonstrated that there can be a mismatch. 51 percent of the respondents in this study stated that appliances do not match their expected lifetime. Marcus et al. (2020) also highlight this dimensional thinking while introducing an additional dimension to it – *perspective*. It is stated that users prefer a longer lifetime than five years on mobile phones and tablets, whereas they currently replace them after two years due to the degradation of the battery. A design enabling battery change could prolong the lifetime of the products, which is desired by users. However, such a design could in some cases be the opposite of what the manufacturers prefer – based on their economic incentives. This means there is a mismatch between these desired lifetimes.

Product developers sometimes inappropriately tend to design around the belief that product lifetime extension always is beneficial. However, one must consider both product- and sector-specific aspects across the whole life cycle of a product. Products such as washing machines or other energy draining

Circular Economy	Strategies		
Linear economy Rule of thumb: Higher level of circularity = fewer natural resources and less environmental pressure Increasing circularity	Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product.
		R1 Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
	Extend lifespan of product and its parts	R3 Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of materials	R8 Recycle	Process material to obtain the same (high grade) or lower (low grade) quality
		R9 Recover	Incineration of materials with energy recovery

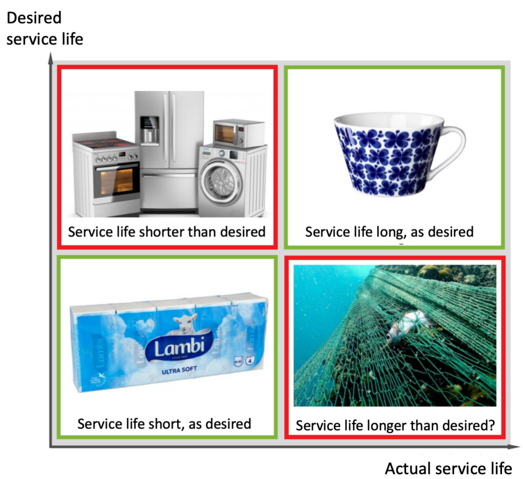

Figure 1. Illustration of the 9R Framework based on Potting et al. (2017), left. Graph of desired service life vs. actual service life (Almefelt, 2020), right.

products (in the usage phase), might not benefit from life extension, if more energy efficient solutions are developed over time (Marcus et al., 2020). Based on theory, Van Nes & Cramer (2006) suggest a method in line with this reasoning called the *Ecological payback period*. This method's goal is to optimize a product's lifetime from an environmental and/or **resource** perspective. The method calculates a point which indicates when it is beneficial to replace a given product. Two empirical studies focusing on the environmental and/or **resource** perspective are Bakker et al. (2014) and Kagawa et al. (2008). Bakker et al. (2014) investigated the optimal lifetime of refrigerators and laptops, but their study consists of a method different from the *Ecological payback period*. However, they have a similar a mindset. In this study, they concluded that it was beneficial to prolong the life of both laptops and refrigerators. The study by Kagawa et al. (2008) was conducted in Japan between 1990-2004 where the goal was to investigate whether it was beneficial to prolong the lifetime of vehicles compared to purchasing new vehicles. They concluded that it would be beneficial to prolong the lifetime of vehicles, during this period of time and context.

Haug (2016) highlights the importance of including the **user** aspect when designing products for a certain lifetime, which is based on two main reasons. Firstly, the **users** are the ones that use the product and affect the overall wear of the product, hence influence the real product longevity. Secondly, the **users** are the absolute deciders of when they deem the product obsolete and thereby replace it. Cooper (2004) suggests that a product can become obsolete and replaced for many reasons; technological, psychological, and economical obsolesce to mention a few. Selvefors et al. (2019) suggest that a product must be designed with the **user** in mind, and that viewing a product's lifecycle from a **user's** perspective can aid in this. A typical cycle of distribution-use-end of life, products can instead be seen and understood from a lifecycle of obtainment-use-riddance.

More interest regarding companies' roles in the transition towards a circular economy has emerged, and different **business** models have been suggested, along with discussions of how and why companies need to adapt to a circular economy. Stahel (1997) started to discuss this early. More specifically, one idea regards strategies where companies sell the use of goods, or services, rather than the objects as such. Stahel's (1997) main points were that companies need to start to apply more cyclic or circular thinking in their **business** and reassess how they currently work. De los Rios & Charnley (2017) highlight the importance of how companies more holistically must reassess how they conduct **business** and adapt appropriately in order to follow the recently started transformation. Allenby (1997) stated: *"The fundamental purpose of a for-profit corporation in a free market economy is to make money for its owners, that is, the shareholders"*. This is still relevant today since it highlights the fact that companies must adapt their **business** in line with the transition in such a way that they still are profitable.

Several approaches can help product developers to prolong the life of products and the resources they contain. Potting et al. (2017) present five general approaches, illustrated in Figure 1, left. These can aid in extending the lifespan of products and their parts. Bakker et al. (2019) provides six specific design strategies; *Design for Attachment and Trust*, *Design for Durability*, *Design for Standardization and Compatibility*, *Design for Ease of Maintenance and Repair*, *Design for Adaptability and Upgradability*, and *Design for Dis- and Reassembly*. These six strategies can be used to redesign a product, and are argued to promote both a circular design along with a longer lasting product design.

Authors provide several views on product longevity, introducing various aspects to consider. There can be a mismatch between **real** and **desired** lifetime, and it is not necessarily desirable to always prolong the lifetime of products in their current state, depending on *perspective*. For example, the lifetime could be desired to be three years – from a **user** perspective, assuming the user is sensitive to trends and emerging technologies. The lifetime could instead be desired to be longer than three years – from a **resource efficiency** perspective, assuming the product has a low energy consumption. The lifetime could also, in opposite of these, be desired to be shorter than three years – from a **business** perspective, assuming this increases the company's profit. This would result in a mismatch between the **desired** lifetimes.

Moreover, products can become obsolete and replaced for various reasons, and an understanding of this is important. Furthermore, one can also discuss how the product's lifetime itself can be defined. The product life cycle is typically seen as production-usage-end of life. While considered true – from a manufacturer's point of view, the life cycle could instead be seen as obtain-use-riddance – from a user's point of view. We would like to argue that both views should be considered in order to fully grasp a product's life cycle. In addition to this, products can be characterized to consist of material resources, such as parts and components. While considered true – from a simple point of view, products can also

be characterized to consist of both material as well as immaterial resources – from a more complex point of view. Most naturally, it should be out of our interest to maximize the utilization of these.
To summarize, it is clear that product longevity is multifaceted and can be managed in different ways. However, while different solutions are provided, there is seemingly a research gap. Currently, there is no literature where all of these aspects are managed and discussed in relation to each other, nor combined into a wholesome definition or mindset. This emphasizes that there is a need of a framework addressing this issue.

4 PROPOSITION: THE DEVELOPED DESIGN FOR LONGEVITY FRAMEWORK

The developed Design for Longevity framework presented in this section is a method or tool for product developers to implement in order to actively design for a specific longevity, given any durable good within the consumer industry. The framework consists of; a definition, a mindset of how to anticipate and realize Design for Longevity, and two supporting tools.

4.1 Definition of Design for Longevity

A definition of Design for Longevity has been developed based on the collected and analyzed literature. The definition aims to help product developers to actively consider product longevity when making decisions regarding the product's design.

> *Design for Longevity includes the careful consideration of how a product's life cycle is defined. Longevity is defined as for how long a product can perform any desired function over a certain period of time, either as a set of resources or as an object that serves as a means to provide a function. Design for Longevity aims at designing products with an optimal lifetime, where optimal means taking the user, the business and the resource efficiency perspectives into account when designing the life of a product.*

4.2 Design for Longevity Mindset

The definition of Design for Longevity provides product developers with a nuanced view of product longevity in order to actively consider it. However, realizing Design for Longevity is not considered trivial, and it is therefore broken down into smaller blocks. This entails a more wholesome mindset of how Design for Longevity should be anticipated and thus realized, illustrated in Figure 2.

4.2.1 The Adapted Design Strategies and their Relation to the Product Context

The six design strategies provided by Bakker et al. (2019) are included in the framework. The design strategies can have a beneficial impact on a product's life, since they can be used to prolong and redesign a product's life. However, we would also like to state that it is not always beneficial to implement each individual strategy for all products, based on two main reasons. Firstly, it is not possible to implement all

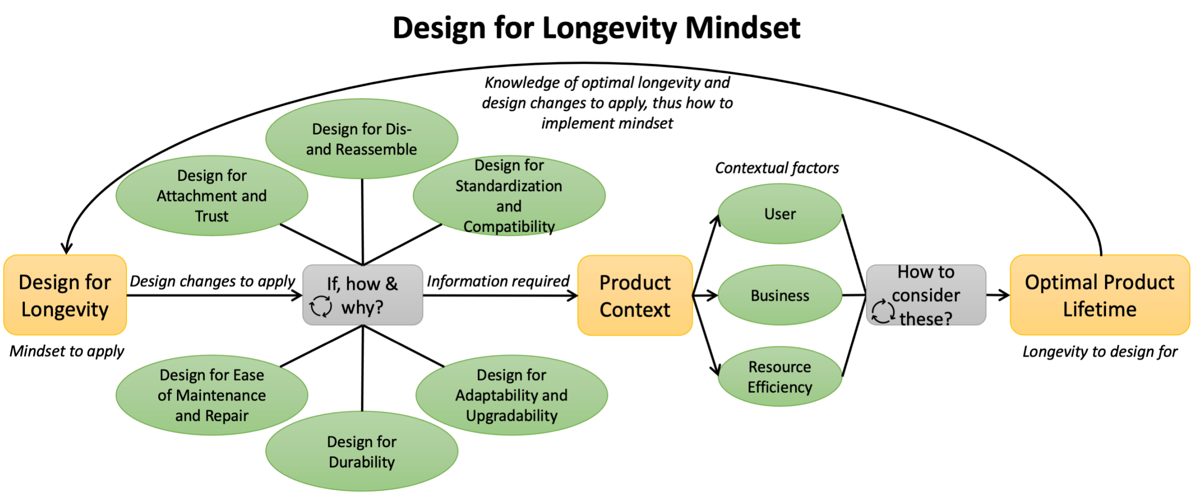

Figure 2. The flowchart illustrates the main blocks of the Design for Longevity Mindset and how it should be anticipated.

strategies on all products, since different products aim to provide different functions. Secondly, Design for Longevity aims at designing a product to provide a certain function, for a certain period of time, meaning that it is not always desired to prolong the product's lifetime. This highlights the fact that the proposed design strategies should be implemented reasonably, and that companies need to analyze and understand their *Product Context*, as well as the design strategies. The six strategies were therefore adapted and reformulated before they were included in the framework. In contrast to Bakker et al. (2019), the new descriptions are formulated, in a concise manner, to provide; the purpose of the strategy, an explanation and understanding of the strategy, and potential benefits and drawbacks. This aims to enable product developers to make justified decisions, with minimum effort, regarding whether and how the design strategies should be implemented when Designing for Longevity. Two of the six new descriptions are provided below to illustrate these formulations.

Design for Attachment and Trust: The strategy is to design the product to evoke attachment and trust between the customer and the product. If the customer associates the product with an own significant value or feeling, it can increase the consciousness of responsibility and obligation to take care of the product. The product's lifetime likely increases because of emotional bonding between the customer and the product. However, there is a risk that an obsolete product remains in the customer's possession for a prolonged period of time, when in fact a replacement of the product would be beneficial from a resource efficiency point of view. **Design for Dis- and Reassembly**: The strategy is to design the product in order to facilitate the process of disassembly and reassembly of components and material from the product. This can be done through increased accessibility of components and material which makes it easier to recover resources. Product architectures developed for dis- and reassembly influence the placement and connection of components, and material selection, most likely to an expense of complexity. It can also be difficult to optimize the components' design and the product's architecture if the process of dis- and reassembly is considered to be implemented in all aspects.

4.2.2 The Product Context and its Relation to the Optimal Product Lifetime

The *Product Context* is a situated set of information, and will differ depending on the product. This aims to emphasize and remind companies that it is important to consider the product out of three pre-defined aspects while designing it. The **user** can be defined as the person that actively consumes or uses the product. The **business** can be defined as the actor that gains value in return of providing the product. Finally, the product both contains and consumes resources as a means to fulfill its function, and the use of these can be measured or discussed in terms of **resource efficiency**. Furthermore, product lifetime consists of two dimensions; **real** and **desired**. The desired product lifetime can and will most likely differ between these three aspects. While trying to homogenize the desired lifetime from the three aspects, it is also important to try and homogenize the two dimensions, real and desired, since a mismatch between these two is non-ideal. Successfully doing this will then result in the *Optimal Product Lifetime*. Altogether, this entails a theoretical definition of an optimal product lifetime.

> *A product's optimal lifetime is the point where the user's, the business's and the resource efficiency's desired and real product lifetimes coincide.*

4.3 Design for Longevity Supporting Tools

To support the implementation of Design for Longevity, two tools were developed; a linear step-wise process as well as a visualization tool.

4.3.1 Design for Longevity Implementation Process

The definitions and elements in the framework are intended to be used to assess an optimal product lifetime and thus realize Design for Longevity. However, realizing Design for Longevity requires the elements to be used and implemented in an appropriate manner. The linear step-wise process, illustrated in Figure 3, right, was therefore developed. The process consists of several steps, and each step in the process requires a set of questions to be answered before it is possible to move to the next step. This ensures that the practitioners collect the appropriate information and knowledge before entering the next step. Completing the process will result in two things; a pronounced optimal product lifetime and the actions required to realize it. A detailed guide of this process has been developed and can be found in Carlsson & Mallalieu (2020).

4.3.2 Optimal Product Lifetime Diagram

Our definition of an optimal product lifetime is first and foremost theoretical, and will therefore most likely be both demanding and difficult to identify, as well as to realize. We provide the developed visualization tool *Product Lifetime Diagram*, illustrated in Figure 3, left, to help companies assess this. The x-axis represents the real product lifetime and the y-axis represents the desired product lifetime. Those parameters can for example be represented as time or use cycles. This model is adapted from Almefelt's (2020) model, but is both refined and more precise, and should thus be used in quantitative measures to map out the product lifetimes. There is also an ideal scenario illustrated with a dotted green line, this line represents the one-to-one ratio to strive for. This occurs when the desired product lifetime is equal to the real product lifetime. The three contextual aspects; the **user** (U), the **business** (B) and the **resource efficiency** (RE), should be indicated as points in the diagram, in their current state. Each point consists of two dimensions, the **desired** and the **real** product lifetime. These should be assessed individually without respect to each other, as objectively as possible. We provide the following developed definitions for the three pairs of coordinates.

U [x]: *For as long as the user actually uses the set of resources to provide a certain function.*

U [y]: *For as long as the user desires the set of resources to be used to provide a certain function.*

B [x]: *For as long as the resources are planned to be used to provide the certain function.*

B [y]: *For as long as the company desires the set of resources to be used to provide the certain function.*

RE [x]: *For as long as the set of resources can be used to provide the certain function.*

RE [y]: *For as long as the set of resources should be used to provide the certain function.*

The purpose of the *Product Lifetime Diagram* is mainly to serve as a mediating tool and stimulate a discussion regarding the product's different lifetimes. The *Optimal Product Lifetime* can be elicited from the three points converging into an optimal point, which is a result of implementing the design strategies to different extents.

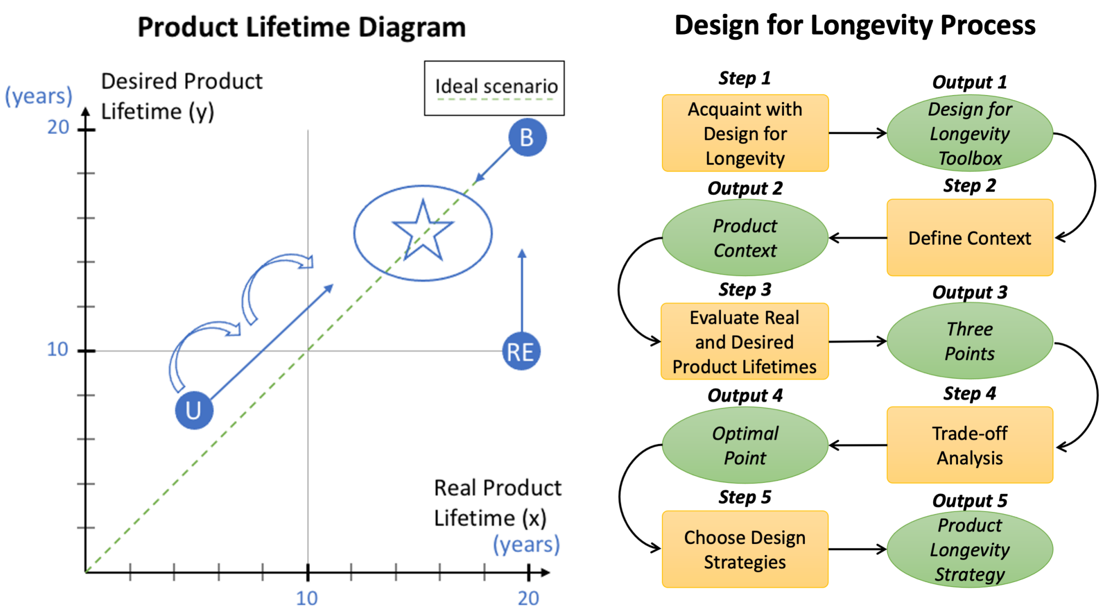

Figure 3. The Design for Longevity Process, right, consists of five steps that help practitioners to appropriately use and implement each element in order to realize Design for Longevity. The Product Lifetime Diagram, left, can be used when analyzing a product's lifetimes. The blue animations illustrate the results of applying the Design for Longevity Process on a hypothetical example case of a passenger vehicle. The axes represent time in years. The points; B, U and RE represent the three corresponding aspects with their current lifetimes. The arrows indicate how different design strategies can be used to converge the different product lifetimes. The circle and star represent the optimal point or area that the lifetimes are converging towards.

The blue animations, seen in Figure 3, left, provide an example which is based on rough assumptions. The example illustrates how the tool can be used to both visualize and analyze a product from the aspects discussed above. Explaining the example case further; Company X manufactures passenger vehicles (internal combustion engines). They have a planned and desired longevity of 20 years, which entails point **B** to be positioned at (20,20) in the graph. Additionally, the manufactured vehicles are also proven to function for at least 20 years. However, because of more energy-efficient vehicles entering the market, it is estimated that a replacement of the vehicles is beneficial after 10 years – from a resource efficient perspective. This means that point **RE** should be positioned at (20,10) in the graph. Further, company X's main customers are trend-sensitive users, and the passenger vehicles are usually replaced after 3-5 years. However, in contrast to this, user studies indicate that company X's customers would prefer the passenger vehicles to feel up to date for at least 7-8 years. This means that point **U** should be positioned at ~(5,8) in the graph. Altogether, this indicates that there is a mismatch between the different lifetimes, clearly illustrated in Figure 3, left. This hypothetical dilemma can be solved in many different ways, and the proposed design strategies can facilitate some of these solutions. For example, one could argue that the vehicles' interior can be up to date by using *Design for Dis- and Reassembly*. More specifically, enabling an exchange of the interior display with a new version – moving point **U** towards the other two. Another possible solution could for example be to implement *Design for Adaptability and Upgradability*. More specifically, enable upgrades on the vehicles' powertrains to make them more energy-efficient, either through software and/or hardware – moving the point **RE** further up. The cumulative effect of many different actions could then result in the points converging towards a certain area – the *Optimal Product Lifetime*, as illustrated in Figure 3, left.

5 EVALUATION AND DISCUSSION OF THE DEVELOPED FRAMEWORK

Both qualitative and quantitative data were obtained from the user study. This data is summarized and discussed below, accompanied by a brief discussion about the research approach.

5.1 Summarized User Data from Semi-Structured Interviews

The Design for Longevity Mindset was considered to be enlightening and highlighted relevant aspects. One interviewee explicitly said that the definition of Design for Longevity contains several components which had been seen before, but never in such a cohesive manner. However, even though the mindset was deemed to be appropriate, more general explanations that clarify the three contextual aspects were desired. This was considered to be needed since it was argued that these will differ for different products. For example, emission standards can be an important factor for a passenger vehicle, affecting all contextual aspects. However, it can be of less importance for a bicycle. **The Design Strategies** were considered to be relevant in regards to Design for Longevity. The adapted descriptions contained enough information to provide an understanding of each design strategy, along with its benefits and risks. The interviewees found it relevant to acquaint themselves with the design strategies before addressing the product lifetimes. This helped them to generate an understanding of how different design strategies can affect a product's lifetime. This was also explicitly expressed to be needed since there is usually a various degree of knowledge of the practitioners involved in this type of process. **The Optimal Product Lifetime Diagram** was considered to be a helpful tool to visualize and stimulate a reflection over a product's optimal lifetime and how the product lifetimes vary for the same product. It was explicitly said that the tool was easy to use, and the contrast between desired vs. real life was also deemed to entail an interesting reflection on the product. However, the reflection was occasionally considered difficult, and it can be difficult to distinguish between desired and real lifetime. One additional issue was that it was considered difficult to determine the precision of the results using the diagram. **The Design for Longevity Implementation Process** was deemed applicable on the provided example case by most of the interviewees, but some considered a passenger vehicle to be too complex and suggested that it instead could be used on separate components in a passenger vehicle. The interviewees could see possible improvements. The process contains several steps, where each step requires a set of questions to be answered. These questions need to be adapted for different products. Some products need more data to obtain the appropriate precision while not becoming too time-consuming or complex. The amount of data and as well as the involved competence in the process have a large impact on the final result. Therefore, the product developer implementing the process needs to have the appropriate experience and knowledge in order to achieve a proper result. The product developer most be able to conclude; when, what and where assumptions can be made, since the accuracy and precision of the process may decrease if the data is built on inappropriate assumptions. Finally, the framework was considered to serve its overall goal. Seven out of eight interviewees said that they could consider themselves to use both the process and its tools to assess an optimal product lifetime.

5.2 Benefits and Drawbacks of Proposed Design for Longevity Framework

The framework can bring several benefits, the most distinguishable are the possibilities it brings in terms of being able to actually visualize and reflect upon complex matters, such as a possible optimal product lifetime. The framework also highlights key aspects and definitions that can ease the task of determining an optimal product lifetime itself, without necessarily using the proposed process and tools. The framework also entails possible drawbacks that need to be discussed. The overall framework will have a variation in how extensive it is to implement, depending on the product. More complex products will most likely be more demanding, and require more data. The data which is collected and the information it contains will also have an impact on the result. This means that both the amount of data along with its information will affect the precision and accuracy of the results, and it is therefore a pronounced uncertainty regarding the overall extensiveness of implementing Design for Longevity. The practitioner must therefore be able to conclude how extensive the process needs to be, since this will affect the results.

5.3 Validity of the Proposed Design for Longevity Framework

The exploratory literature review served as the base when developing the elements in the framework. It is difficult to conclude if enough literature has been collected or not, there is however considered to be a big variation regarding the literature collected. Many different views on product longevity were merged into a complete framework, which is deemed to increase the credibility of the results. Furthermore, a user study aiming to test the acceptance within the industry was used to verify the framework and increase the credibility further. The user study's results were obtained using a Likert scale evaluation. The results indicated a positive attitude towards the framework and its elements, thus concluding that the interviewees accepted our framework. The framework is therefore considered to help companies to Design for Longevity, which was the paper's overall goal. However, it is important to distinguish between acceptance and reality. Further, professionals within industry accepting the framework do not necessarily mean that implementing Design for Longevity actually identifies the real optimal product lifetime, and designs for it. This makes it troublesome to make a conclusion about the framework's validity. The framework needs further validation through testing, since it has only been tested on example cases.

6 CONCLUSION & RECOMMENDATION

The overall goal of the paper has been to develop a framework that helps companies to Design for Longevity, given any durable good within the consumer industry. The goal fulfillment is evaluated in relation to the formulated criteria in Section 2. The framework; was concluded to be **understandable**, all interviewees understood all elements and their purpose, but requested more detailed descriptions. It was also concluded to be **applicable** on a passenger vehicle. However, a few considered a complete passenger vehicle to be too complex, and instead saw it as applicable on specific components. The **extensiveness** is difficult to conclude on, since it was argued that its implementation will differ for various products. **Experience** was argued to be important, and descriptions of the design strategies supported those with less experience. The **visual design** was considered logical, and the *Product Lifetime Diagram* was explicitly praised. The **usefulness** to determine an optimal product lifetime is difficult to conclude on. It was deemed as supportive, but the precision of the result and uncertainties was a considerable issue. It was concluded to **support** in identifying possible design changes. Altogether, the paper is therefore concluded to fulfill its overall goal. However, we propose the following future work for further improvement and validation.

- The framework needs to be applied on more cases to test its applicability on a larger span of durable goods along with validating the results of implementing Design for Longevity.
- The framework needs to be evaluated in larger focus groups to validate its usability and find further improvements.

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