Designing for circular business models

Future adaptive design: a heuristic for designing products suitable for circular business models

Bilaga 1: Promising examples and methods for design for circular business models built around long-lasting products

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Designing products that can adapt to changes over time is crucial for preserving value in circular business models and avoiding premature product obsolescence. Increasing adaptability, however, often involves significant additional investments whose uncertain future returns increase business risk.

Research provides theory for topics related to design for circular economy but easy-to-use guidance for how to undertake this in practice in early phases of business development and product design is scant. This project contributes just this, knowledge about how companies can mitigate product-related risks related to circular business models.

The biggest barrier to achieving energy-efficient FA product-service systems is the dominant linear business logic of established manufacturing companies as business logic controls the design logic or the design choices that define the product’s energy consumption and environmental impact during the life cycle. Of course, there are additional factors that should be considered when developing the business model including customers and users’ attitudes, incentives and behaviors.

**Main results from this project**

- An improved methodology for how to combine circular business innovation with product service design in early development phases that can offer predictable business risks has been developed and pilot tested in several manufacturing firms
- A potential for radically reduced environmental impact has been identified based on scenarios for extended longevity for energy using products as elevators and cars
- Several challenges for designing circular business models and adaptable products have been identified including challenges related to modularity, interoperability and certification
- A range of promising examples from manufacturers has been identified where mainly startups are in the forefront with design for longevity

**In addition**, the project resulted in a deepened understanding about how incumbent manufacturers of energy-using products can explore and develop both circular business models in conjunction with suitable products and supportive services. By extended usage time for elevators and personal EVs there is a potential to reduce environmental impact (CO$_2$) by as much as 70%. However, realizing these reductions will require big changes in the current business and design logic in industry, as well as customer acceptance for long-lived products.
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Introduction
Extended product life

During the emergence of mass production and consumption, the manufacturing industry turned industrial production into a mechanism for rapid acceleration of global material and resource usage by applying linear business model (LBM) logic that is considered wasteful by today's standards. Yet, recently, calls for an alternative model—a circular economy and circular business model—have been made to help address the environmental challenges arising from such LBM and decouple resource consumption from economic activity.

In a circular economy, product life extension is widely considered one of the most promising means of slowing down resource flows and limiting the inflow of materials and energy into our economic system.

As a provider of a service, the design of the products used is central to creating profitability, while at the same time, the product's environmental impact is greatly affected by longevity and the amount of function delivered.

Kasarda (2007) characterizes the onset of premature product obsolescence as the inability of a product to adapt to one of more hard-to-predict changes in product context that occur over the (planned) duration of its useful lifetime.

As such, a firm's ability to design products that can adapt to changes that will or might occur during the usage time could help retain product value, thus increasing their willingness to adopt product life extension (PLE) circular business models and supporting the transition to a circular economy.

As a service provider, you can try to predict many use situations, but sometimes surprises like this—an E-scooter submerged in salt water that probably will require exchange of the electrical system—arise. Due to rough use and wear and tear, E-scooters used in service pools are known to have very short functional lives, as low as a couple of months (Hollingsworth & Copeland, 2019).
Product lifetimes are trending downwards for many energy-using products

- Life expectancy for personal cars: 200,000 Km & 10 years
- Life expectancy for elevators: Less than 20 years
- Life expectancy for smartphones: from 18 months
- Life expectancy for white goods: 10 years
Potential related to extending product life:  
Possible impact reductions for Vehicles, Furniture, Textile

Electric vehicles >(-)50% CO₂-e  
RISE Sustainable Business, ongoing research in FADEV Project material 2021
https://www.ri.se/sv/vad-vi-gor/projekt/framtids-adaptiv-design-for-elfordon-fad-ev

Clothing >(-)50% CO₂-e  
Linking circularity metrics at product and society level (LinCS), Naturvårdsverket project, 2021

Office chairs >(-)30% CO₂-e
https://cirkularitet.se/wp-content/uploads/2019/02/H%C3%A5llbarhetsanalys-av-cirkul%C3%A4ra-m%C3%B6belfl%C3%B6den.pdf
Goals & scope
Scope

This project aimed to test and validate a framework for parallel development of circular business models (CBM) and future adaptive products (FA) with a potential to be in use for longer in a CBM and thereby give a potential for capturing stable revenues and climate/environmental benefits.

The proposed frameworks for Circular Business Model Innovation (CBMI) and Future Adaptive Design (FAD) contributes to existing research on circular business models and circular design by providing a heuristic for addressing challenges encountered during CBM development through the co-design of products and CBMs.

The aim is to offer practical support for multidisciplinary developing teams by bridging the gap between business and design criteria in early circular business model innovation phases. This is because the framework reduces the complexity of traditional adaptive design research, making it more suitable for use in early CBM innovation discussions.

Furthermore, the frameworks provide a common language for business developers and designers to explore how profitability and product longevity can go hand-in-hand in CBMs. This could help facilitate internal company discussions related to the costs and benefits of designing products for increased longevity, and shifting from a product-dominant, to a service-dominant logic.

Product dominant logic:
Value capturing at first point of sale and from spare parts & re-occurring maintenance needs

Service dominant logic:
Value in use with high uptime. Value losses from low quality and high costs for spare parts & maintenance
Theoretical background
Product lifespan as strategic business choice

Henry Sloan, the CEO of GM between 1923 and 1946, suggested that: “The business of business is business”, probably with the assumption that the main reason for companies to do business is to earn money and make a profit, and in the process, staying alive on the market.

In a business environment where continuous sales, new products, and short life are rewarded and integrated into the business models of companies, design and marketing play a central role as the engine of continuous product innovation. Planned obsolescence allows space for constantly new products on the market (Slade, 2006).

Planned obsolescence for consumer goods has been practiced since the late 1920s (see for example Waldman, 1993, Packard, 1960, or London, 1932), pioneered by the car industry. The main reason for built-in obsolescence was to increase consumption (Bulow, 1986), a strategy practiced by the fashion industry since the 18th century, but developed for capital goods during the great depression. The fashion system, to launch new collections for every new season, was adapted also by the car industry in the 1920s and became an important strategy for many other consumer goods that are making up consumers’ lifestyle and identity.

Planned obsolescence can be realized via several dimensions. For example, aesthetic obsolescence can be realized by introducing new styles making the old product look old-fashioned. The producers of clothes excel at this strategy, making clothes synonymous with fashion. We now even refer to it as the fashion industry rather than “clothing industry”. Another form of planned obsolescence is technical, when the lifespan of a product is shortened on purpose, for example, with light bulbs (Avinger, 1981) or white goods, although the empirical evidence of shortened lifespans on purpose remains limited.

“I would have the Government assign a lease of life to shoes and homes and machines, to all products of manufacture, mining and agriculture, when they are first created, and they would be sold and used within the term of their existence definitely known by the consumer.

After the allotted time had expired, these things would be legally “dead” and would be controlled by the duly-appointed governmental agency and destroyed if there is widespread unemployment.

New products would constantly be pouring forth from the factories and marketplaces, to take the place of the obsolete, and the wheels of industry would be kept going and employment regularized and assured for the masses.”

Article by Bernard London, (1923) arguing for legislation in favor for planned obsolescence
Current barriers for product longevity

Modularity in a cost-efficient linear production logic is achieved through a segregated product architecture to offer multiple product variants and mass customization that could be managed in mass production. Modularity and is usually considered as a key enabler in a circular design to achieve repairability, upgradeability, re-manufacturability, and dismantling, as modularity enables parts or groups of parts (modules) to be swapped or replaced, without affecting the rest of the product. Other techniques to execute modularity include clustering – where like parts are grouped with other like parts, and platform design, approaches where sub-components share a common base platform.

However, while many authors view modularity as a core part of adaptable product design, modularity is not only used for achieving product adaptability, and drivers for achieving a cost-efficient production in the production phase do not automatically enhance the adaptability of products during their use phase. For example, the order of module assembly may not be optimized for replacement. Even if products can (as for vehicles) consist of ten thousand components, many of these modules may be assembled through techniques such as welding and gluing, leading to more time-consuming and costly upgrades. Moreover, the clustering of many functions in one component often creates huge cost barriers in repair. This is especially relevant in consumer electronics. E.g in Apple Macbooks from 2013, hard drives and RAMs is upgradable, while in later models clustering of components to one main printed circuit board. Thus, making repairing difficult as illustrated by iFixit[1] and a less cost viable option.

In the example above, the left lightbulb in this car is quite easy to replace when broken. Although, on the right side much more difficult, due to the placement of the battery preventing access to the headlight module.

In cost efficient mass production, automatization is an important driver, as well as modularity to achieve many product variants. However, in the assembly phase, assembly methods such as welding and gluing, the order of assembly affect the practical possibilities for and costs for repairs and upgrades on the aftermarket. Photo by Lenny Kuhne on Unsplash

In consumer electronics, gluing parts is commonly used as assembly methods to achieve efficient production and reliability. Although, it comes with the price of difficult and time-consuming repair operations. The image shows the “iOpener”, a heat pillow designed for opening glued Apple products, including ipads, etc. Image iFixit.com


Led technology for headlights in cars is both energy efficient and has a potential for use for 10 years. However, as the LEDs are fixed to the light assembly, damage to the front layer results in increased costs for exchanging the whole module that could cost 1000€ or more. Such approach to modularity can drive premature obsolescence more many parts instead of just one.
Business Models & Circular Business Models

Business models are often intangible and companies can run multiple business models in parallel. Above is a categorisation of four major types of circular business models. In this research about design for longevity, the focus is on the 'product as a service model', i.e. that a manufacturing firm keeps ownership of produced product and provide them as a function or performance.

Business models are often intangible and companies can run multiple business models in parallel. Above is a categorisation of four major types of circular business models. In this research about design for longevity, the focus is on the 'product as a service model', i.e. that a manufacturing firm keeps ownership of produced product and provide them as a function or performance.

Business Models & Circular Business Models

The business model of a firm can be understood as an image or a blueprint of the "core" logic of a firm. In other words, how the firm does business. A business model reflects the management's hypothesis about value creation, by solving potential customers wants and needs, and identifying how to organise, get paid, and make a profit for delivering such values cf. (Foss & Saebi, 2015).

Circular business models are expression of a "stock-based economy", or an economy that builds on a different profit-making logic than the "linear flow-based economy."

In circular business models, profit is generated by providing access to a stock of products or by the utility that a stock of products can deliver. Therefore, the stock must be considered attractive for as long, and for as many users, as possible.

The longer time each unit in the stock can deliver utility, the higher the revenue and profit will be generated. Hence, it is paramount that the designers are incentivised to make products desirable over time. As such, longevity and extending the useful life of products are a key focus for circular business model research.

An extreme situation would be that manufacturing companies stop producing products, retain their ownership until their end-of-life and instead merely sell their access or performance. To know more about other ways to design stock-based (circular) business models, see "The Performance Economy" by Walter Stahel, 2010.

While there are numerous definitions of circular business models, several types can be identified:

1) Circular supply business models: where secondary materials (e.g., recycled materials) are used instead of primary material inputs;

2) Resource recovery business models: where materials are recycled (for reuse) via renewable energy;

3) Product life extension business models: where the useful lifetime of products is extended through design and enabling second life (e.g., repair or remanufacturing);

4) Sharing business models: where increased utilisation of products is enabled via shared use/access/ownership (often though digital platforms)

5) Product as a service business models: where customers are given access to products (rather than ownership, e.g. renting)
Circular principles in practice
Designing business models and products by combining strategies for:

- **Slowing down of materials & resource flows**
  Extend the longevity of products used by reuse, repair, upgrade, adapt and recontextualize.

- **Close material loops**
  by material recycling of surplus materials from production or post-consumer usage and circulate them so that they can preserve their material properties and economic values.

- **Narrow flows**
  by using fewer materials, energy, water, chemicals by efficient technologies & production processes, during product usage and recirculation

- **Use renewable energy**
  to run the circular products and services throughout their lifecycles as solar, wind, water, etc.

- **Regenerate**
  by adding or substitute problematic ingredients with safer ones for materials and production processes, product usage, and when closing loops.

- **Also inform**
  about financial, ecological, and customer benefits from your circular products and services.

- **Including keeping track** of your products health and health history

Sources: adapted from (Konietzko et al., 2020; Bocken et al., 2016)
Drivers for Premature product obsolescence

Product life extension is for many products the circular strategy that has the potential to yield climate/environmental benefits, and there is a growing toolbox for product designers to make it happen. However, due to the intertwined relationship between business and design logic, product life extension is not just a product design activity.

From a product design perspective, slowing resource use is relatively straightforward and already available through design tools, such as the DfX-methods[1] focused on easy disassembly, recycling, modularity remanufacturing, upgradability, etc. These tools offer support to designers with practical guidelines for designing products for desired characteristics. Thus, changing design logic for slowing resource use (e.g. product longevity) is well-supported by previous work and could be seen as a doable engineering activity. However, even if the product design is responsible for the major climate & environmental impacts over the lifecycle of a product, they can’t control what happens with the product in real-life usage, if this has not been supported by business logic that actually can enable the product to realize it’s embedded potential.

Although, even if products can be designed for longer life they will inevitably be exposed to changes in the surrounding world that will risk making them premature obsolete.

Products that cannot withstand changes during the usage period will use risks being outdated prematurely and thus reducing in economic value. Thousands of kronor for functional and timely products are then reduced to a few kronor for material recycling. At the same time, an extended service life provides great climate and environmental benefits. The reasons why products are outdated prematurely can be due to one or combinations of the four changes described in the table to the right that can risk making the owner or user of the product judge it to be unsatisfactory, put to idle in storage, discarded, and replace it with a newer one.

<table>
<thead>
<tr>
<th>Type of Future Uncertainty</th>
<th>Description</th>
<th>How Does This Impact Circular Business Models (CBMs)?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic obsolescence</td>
<td>Discarding products due to product appearance; caused by changing tastes, e.g., fashion changes, or product states, e.g., scratches and blemishes</td>
<td>CBMs should consider a product’s aesthetics over its entire lifecycle</td>
</tr>
<tr>
<td>Technical obsolescence</td>
<td>Discarding products due to technical performance; caused by mechanical failure (e.g., due to wear or accidents) or the introduction of technological innovations that cause existing products to become perceived as inferior and lower performing</td>
<td>Products in CBMs should be able to be repaired and/or upgrade to and be compatible with new technologies</td>
</tr>
<tr>
<td>Social obsolescence</td>
<td>Discarding products because of changing societal trends or legislation, e.g., existing products are unable to comply with new certification rules or emissions legislation</td>
<td>Products in CBMs should be able to adapt or adjust to changing social trends or legislation</td>
</tr>
<tr>
<td>Functional obsolescence</td>
<td>Discarding products due to a mismatch between product and user needs; caused by a product’s inability to meet changing user needs, e.g., need for increased space</td>
<td>Products in CBMs should address user’s changing functional requirements</td>
</tr>
<tr>
<td>Economic obsolescence</td>
<td>Discarding products due to the costs of a product in use; users may discard products prematurely if cost of ownership, e.g., maintenance or repair, increases and/or lower cost product alternatives are available</td>
<td>CBMs should consider a product’s costs over its entire lifecycle</td>
</tr>
</tbody>
</table>

References:
Product design with a potential to resist premature obsolescence

In circular product design envision:

A system with a product architecture of individual modules, being separable in interconnected layers

Different life-lengths of these modules due to aesthetical, functional, technical and social changes

What factors that risk making some modules premature obsolete?

Physical products as a platform for continuous service innovation that can keep the product in use for longer

Who could be potential customers for the various modules in a sequence over time, even if being used?

What will it cost to realize a product architecture that is based on circular principles, for longevity?

Products suitable for circular business models must be aligned with both a circular business and design logic, that are co-developed in early development phases. An important starting point is setting a vision that based on circular principles can be used as a platform to backcast a desired future state of the company and its products, together with the value chain.

Read more about design for future adaptable products at: https://www.ri.se/en/what-we-do/expertises/future-adaptive-design-circular-economy
Product adaptivity

Rather than view products as something produced at a specific time with set conditions, FAD views circular business models and products as ‘time fluid’, i.e., being able to adjust and adapt over time to forces that have traditionally been exogenous to CBM innovation. Thus, FAD aims to assist companies in designing their products with sufficient potential to be adjusted and changed according to exogenous conditions unknown at the time of design and production, thus helping to reduce business risks in CBMs.

FAD draws from the established research field of Adaptable Design identifiable in design engineering literature that initially focused on managing complexity from increased demand for product customization in mass production. Adaptable design is described as a 'Design for X' paradigm (Gatenby & Foo, 1990), an umbrella term that covers many design philosophies, practices, and methodologies to help draw designers’ attention to specific product characteristics (i.e. the ‘X’).

Benabdellah et al (2019) categorize existing DFX methods into five categories: a design for service; design for the supply chain; design for quality; design for safety; and design for manufacture and assembly. Here adaptable design falls under the latter category, due to its initial application in production.

Two main approaches to adaptive design are identifiable in literature: design adaptability and product adaptability.

Design adaptability is a design strategy for production. It focuses on creating designs (i.e. blueprints or CAD models) that are easily adjustable, thus increasing production efficiency. The focus of product adaptability, on the other hand, is on the usage phase.

Considering the importance of prolonged product usage in circular business models that extend product lifetimes, we here focus on product adaptability.

Figure x: "An adaptable "whole" (a system) that can survive through time by adapting to changes in its environment”. Just as organism in the ecosystem Adapted from Checkland & Poulter, (2010)
Building blocks for adaptability

Product adaptability design methods consider several elements: flexibility, upgradability, and modularity. Uckun et al. (2014) also argue for the inclusion of reliability and robustness. It is important to note, however, that robustness and reliability alone do not result in an adaptable product. Even though robustness and reliability generally contribute to product longevity, it is the product architecture that allows for or prevents adaptability.

Based on Gu et al. (2009), the three main product adaptability design methods are defined as follows:

- **Flexibility**: the ability of a product to perform a different function without significant alteration
- **Upgradability**: the ability to apply changes to a product to achieve better performance and meet new needs
- **Modularity**: developing a product to have a segregated architecture that allows parts and sub-components to easily detach
- **Product adaptability** can be either specific or general. Specific adaptability is limited to adaptions for (future) changes that are predictable.
- **General adaptability**, on the other hand, provides greater future change potential, enabling products to adapt to needs and requirements unknown at the time of design.

Adaptable design research provides a useful starting point in helping to develop and establish such guidelines. Yet, to date, there appears to be little effort focused on combining adaptable design with circular economy research. This could be in part because traditional adaptable design approaches present a high threshold for usage during CBM innovation processes. Most existing CBM innovation tools are qualitative in nature and focused on generating initial concepts, whereas adaptable design methods are the opposite: quantitative and detailed-oriented. Thus, the technical and quantitative approaches required in adaptable design may be prohibitively challenging for use in CBM development.

Unforeseen requirements

Figure x: Building blocks for achieving product adaptability. These building blocks help address obsolescence and future uncertainties in different ways and to different degrees. Durability can be viewed as the foundation on which flexibility, specific adaptability, and general adaptability rest. While durability addresses common design requirements are known to be relevant long term, the other building blocks deal with future anticipated and unforeseen requirements over a product’s functional life.
Profit development in a circular business model over time vs linear sales

Product life extension is expected to provide firms with economic opportunities; by adopting circular business model, firms may be able to preserve much of the economic value added to products during their production and reduce the environmental burdens associated with these products. Thus, longer product lifetimes are considered central to the value creation logic in CBMs.

Producers may be able to better address different customer needs through customization, while product owners (either customers or companies) can save costs if increased functionality through adaptable design allows them to avoid buying or making new products. In addition, environmental benefits can be achieved if new product production is avoided by replacing only a few new modules or components in already existing products.

However, undertaking adaptable design also entails business risks. It may increase costs for companies because of additional product development processes or increase the use of expensive materials and production processes. Product designs must also be assessed and modeled quantitatively by engineers, and even after adaptable design is adopted and executed, it can be challenging to determine the actual financial benefits. Uckun et al. suggest companies take a calculated risk when designing for adaptability, working towards an ideal long-term scenario where future income earned by being able to adapt the product and reduce future costs (or supply risks) might turn out to be lower than the initial design and manufacturing investment.

An easy way to early investigate the financial potential of putting an existing linear product in a circular business model (e.g., a PaaS-model, product as a service) is to take the existing linear retail value (the sales price) as cost since all existing costs are the covered in that calculation (the linear margin is then already earned before the PaaS business begin). Then all needed cost over time in order to keep the attractiveness of the product need to be added and thereby secure the willingness to pay for the function.

The figure below shows an example where the cost of a product that goes into a PaaS model is depreciated to zero the first three years and the profit is around zero these years. After that there are no product cost to depreciate anymore but instead service, repairs and upgrades. But these cost items are lower than the cost of producing a new product and if the willingness to pay can be kept fairly high a product can generate quite some margin over time in PaaS models.

It becomes clear how important longevity design and design for smaller/easier service and repairs are in these business models since that will decrease cost and increase profitability.

Figure x: Product design for longevity and lower cost for service and repairs will contribute profit over time.
Tools for exploring FAD in CBMI
Process for facilitating circular business model innovation (CBMI) and suitable product design.

To facilitate a learning on how business models and products can be designed in parallel with the intention to capture value from long-lasting products, a development process is proposed as follows by the CBMI frameworks (Figure x):

The CBMI framework builds on lines of thought by scholars, c.f. Simon (1996), Brown and Martin (2015) and Checkland (2011), that see design as a transformational process of changing a current state to a desired one. In this context, the outcome of a CBM being based on an existing stock of products. This normative stance is derived from principles for backcasting (Broman and Robert, 2017).

Necessary preparations before starting the CBMI process for those appointed responsibility for it, or even if self-initiative is taken, the role as a “change manager” is to get buy-in from the top management, and a commitment that the top management on a regular basis will take an active role in the BMI process. This should be followed by setting up a separate group, “a dedicated team” consisting of people with necessary competencies and functions from business development and design, that is given the prerequisites to distance themselves from the DBL in the firm’s current operations of the “performance engine” (c.f. Govindarajan and Trimble, 2010).

This team can then start to build awareness and understanding about the current (problematic) state embedded in the organisation’s DBL and the rest of the value chain. The interventional approach in the CBMI process is derived from the methodology for lean start-up and Customer Development (Ries, 2011; Blank and Dorf, 2012), as radical and architectural BMI will impose top management to step into unknown territory and with a lack of prior experiences or successful examples to lean on. In the Customer Development process, a dedicated team builds knowledge by doing small-scale and cheap hypothesis testing and iterations, rapidly and in close contact with potential customers, to reveal essential barriers and make failures come at a low cost early in the process, thus preventing more expensive failures later on.

Figure x A process for circular business model innovation and product design aiming at slowing down resource flows by product life extension. The framework a) draws from previously presented concepts of design as a change process (Simon, 1969), b) principles for Backcasting (Holmberg and Robert, 2000), c) customer development (Blank and Dorf, 2012), and d) In step 4 the exploration of suitable product-related business risks is carried out in two steps. 1 exploring to use an existing product as is. 2. To use principles for FAD to identify further improvements that can reduce business risks by durability, flexibility and adaptability.
Introducing the FAD framework

To help facilitate the adoption of product life extension business models, a design approach called Future Adaptive Design (FAD) is proposed. Future Adaptive Design emphasizes designing products with the ability to adapt to unknown changes in product context, in order to combat future product obsolescence. As illustrated at right, applying the Future Adaptive Design approach occurs during the ‘Develop’ phase of the CBMI framework.

Future Adaptive Design aims to bridge the product design and business model domains by what we refer to as “financially grounded adaptability.”

The purpose of this approach is to determine the potential business benefits of applying Future Adaptive Design strategies. What additional costs or new revenues can be expected by designing and manufacturing products with Future Adaptive Design in mind? Identifying these trade-offs can help companies make more informed decisions regarding the adoption of Future Adaptive Design strategies.

In this project, four strategies for Future Adaptive Design were identified (shown at right and defined on the following pages). Two strategies are referred to as ‘preventive actions’, meaning these strategies are intended to be applied during the product’s design phase (i.e., before production and use). The other two strategies are ‘curative actions’. This means they are intended to be applied during the product’s use phase.
Four Strategies for Future Adaptive Design

Every Future Adaptive Design Strategy contributes in some way to addressing premature product obsolescence and thus is expected to contribute to longer product lifetimes. Below summarizes how each strategy can be used to help create longer lasting products. Each strategy is further detailed with examples on the following pages.

**Multilayered Modularity & Interoperability**
Ensure product components can be independently interchanged and updated - while also remaining compatible to each other.

**Lifecycle Service Planning**
Plan when product components will need to be exchanged, updated, and replaced.

**Continuous Service Innovation**
Develop additional services or product add-ons that address changing customer needs.

**Cascading Customer Usage**
Find new types of customers and situations where a product and/or its component can have a second life (or more).
Exploring the FAD strategies: Multilayered Modularity and Interoperability

Multilayered Modularity and Interoperability helps result in a layer-based product architecture that supports interventions and updates to a product.

As such, this helps to addresses premature obsolescence by enabling components to be easily exchanged and renewed when they become faulty or obsolete.

Examples of this strategy in existing products are shown at right.

Example of multilayered modularization: The tube frame as skeleton
Image: http://www.axialracing.com/products/ax90020/gallery

Established practices today that increase product related business risks in a circular business model for extended product longevity: The unibody: https://www.sccarallycross.com

Example of not designing for interoperability: New software updates not supporting existing hardware. In a heavy vehicle’s onboard infotainment system, the Spotify app was originally included, but the hardware in the vehicle could not support a newer version of Spotify, and the OEM was forced to remove this application as the hardware was non-upgradable.
Image: https://www.stuff.tv/apple/carplay/review

The bike industry is built upon modular components that have been standardized to a high degree since a long time. Modularity with standardised interfaces for components are key enabler for small bike OEMs to be able to manufacture products without need to negotiate bilateral with agreements with suppliers.
Exploring the FAD strategies: Lifecycle Service Planning

Lifecycle Service Planning helps identify when product components will need to be updated or replaced.

As such, this helps to addresses premature obsolescence by planning for when interventions to a product will need to undertaken.

Examples of this strategy in existing products are shown on the right.

Solid-state drives are more expensive than hard-disk drives. However, Lifecycle Service planning might make companies select solid-state drives over hard-disk drives because they may result in lower overall lifecycle costs. (This is due to not needing replacement over long periods of time due to storage, performance, and vibration-resistance performance.)

The choice of fabrics visual and technical properties are important to combating technical and aesthetical obsolescence in products used intensively. E.g. interior materials in car sharing services being exposed to dirt and require regular refurbishments.

Materials with improved durability as e.g composites, stainless steel, aluminium and ceramics are being used in many applications e.g. in the marine or aerospace industry. Old airplanes made with composites are still in the air, and plastic boats still in use since the 1960ies.

Ceramic bearings that can reduce rolling resistance with 50-70% and that can last 4-8 times, 30 longer than steel bearings (Danish energy analysis, 2013). Considering a change to ceramic bearings could, even if being much more expensive, offer lower total life cycle costs that metal bearings.
Exploring the FAD strategies: Continuous service innovation

Tesla continuously introduces new services for existing vehicles. For example, their release v10.0 offers karaoke, games, and a function where the car can drive to pick-up the driver. If the car is within sight on a parking area. However, it does present limitations for backward compatibility for older models. [https://www.tesla.com/sv_SE/blog/introducing-software-version-10.0](https://www.tesla.com/sv_SE/blog/introducing-software-version-10.0)

Volvo Cars “Slippery Road Alert” was developed from existing user data. The service uses sensor data from vehicle behavior in cold weather conditions to send warnings to other drivers and condition information to road authorities. [https://www.media.volvocars.com/se/sv-se/media/pressreleases/223968/volvo-cars-deltar-i-banbrytande-paneuropeiskt-pilotprojekt-for-delning-av-sakerhetsdata](https://www.media.volvocars.com/se/sv-se/media/pressreleases/223968/volvo-cars-deltar-i-banbrytande-paneuropeiskt-pilotprojekt-for-delning-av-sakerhetsdata)

Farm tools are another example Continuous Service Innovation. Many types of tools can be added on to one specific product (e.g., a tractor). Another example is the cigarette lighter in cars that been converted to an accessories power outlet. Photo by...

Continuous Service Innovation helps companies identify changes in customer needs and what new services or product updates could address these changing needs.

As such, this helps to addresses premature obsolescence by helping to keep the product relevant to changing customer needs.

Examples of this strategy in existing products are shown at right.

Volvo Cars “Slippery Road Alert” was developed from existing user data. The service uses sensor data from vehicle behavior in cold weather conditions to send warnings to other drivers and condition information to road authorities. [https://www.media.volvocars.com/se/sv-se/media/pressreleases/223968/volvo-cars-deltar-i-banbrytande-paneuropeiskt-pilotprojekt-for-delning-av-sakerhetsdata](https://www.media.volvocars.com/se/sv-se/media/pressreleases/223968/volvo-cars-deltar-i-banbrytande-paneuropeiskt-pilotprojekt-for-delning-av-sakerhetsdata)

Farm tools are another example Continuous Service Innovation. Many types of tools can be added on to one specific product (e.g., a tractor). Another example is the cigarette lighter in cars that been converted to an accessories power outlet. Photo by...

New service offerings or updates often have the role in lowering the financial thresholds for customers. For example, leasing schemes are not mainly introduced for keeping an existing product in use for longer. Also, software updates can shorten the life of the hardware. New service offerings for exchanging old for a new product could then be tempting, but usually the buy back options are less viable from the customer point of view.
Exploring the FAD strategies: Cascading Customer Usage

Cascading Customer Usage helps identify new potential usages for products. As such, this helps to address premature obsolescence by maximizing product usage and finding potential new revenue streams for companies. Examples of this strategy in existing products are shown at right.

Tire recycling is another example of Cascading Customer Usage. Swedish company Scandinavian Enviro Systems breaks down tires into their material components and uses these for new applications.

Volvo Trucks in Gothenburg, Sweden, converts electrical bus batteries into solar energy stores for housing. After being used for three years in a bus, the batteries can be used another ten years in the housing.

The detachable body truck is a flexible product that can be used in many applications over time. For example, customers can use it for many tasks, such as using a small excavator instead of a large in construction or using a detachable body truck that can carry various containers that can be exchanged by a lifting arm. Photo by Hiab https://www.akerioentreprenad.se/2018/09/25/nyagenerationens-lastvaxlare/
Summary of Future Adaptive Design strategies and how they address future uncertainty in CBMs.

<table>
<thead>
<tr>
<th>Future Adaptive Design Strategy</th>
<th>What This Strategy Focuses On</th>
<th>How This Helps Address Premature Obsolescence</th>
<th>Related Design Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multilayered Modularity and Interoperability</td>
<td>Designing a product architecture to support interventions that allow for updates and changes over the product’s lifetime</td>
<td>Premature obsolescence can be postponed and reversed if components on separate layers can be exchanged and upgraded. This will be valid for resisting technical, functional, aesthetic, and social changes that risk obsolescence</td>
<td>Design for: Disassembly / reassembly; Compatibility; Interoperability; Modularity; Standardization; Upgradability</td>
</tr>
<tr>
<td>Strategies for Preventive Actions</td>
<td>Planning for when components will need interventions over a product’s lifetime (and when these interventions will take place)</td>
<td>Defines components (and their costs) and technologies that might need to be exchanged and upgraded over in a product’s lifetime, thus addressing economic and technical obsolescence</td>
<td>Design for: Lifecycle; Maintenance; Reliability; Road-mapping</td>
</tr>
<tr>
<td>Lifecycle Service Planning</td>
<td>Identifying emerging changes in customer needs over a product’s lifetime and what can be done to keep the product relevant to users by upgrades of new software or services</td>
<td>Gives customers a continuous contemporary product experience based on the existing hardware, thus reducing their need to exchange for a new product. Especially relevant for aesthetical, functional, and social obsolescence</td>
<td>Design for: Flexibility; Recovery; Service; Supportability</td>
</tr>
<tr>
<td>Continuous Service Innovation</td>
<td>Identifying usages/applications for a product and its components to maximize utility</td>
<td>Provides the product owner with a possibility for a revenue stream from resale of exchanged components, remanufactured components, or recyclable materials. Addresses technical and functional obsolescence</td>
<td>Design for: Multiple lifecycles; Cascaded use; Reuse; Recovery</td>
</tr>
<tr>
<td>Cascading Customer Usage</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the concept of financially grounded adaptability proposed here, product and business model adaptivity are considered option values. The purpose of this approach is to explore costs and potential revenues by designing and manufacturing products with a higher, or lower level, of adaptability to unknown changes in product context, i.e., to determine the business benefits of applying more or fewer Future Adaptive Design strategies.

Managerial decisions on the use of Future Adaptive Design strategies should be informed through estimates of potential economic losses resulting from the occurrence of premature product obsolescence (business risks) versus potential additional revenues gained through the application of Future Adaptive Design strategies. An economic analysis such as the one proposed here (checklist to the right) could be a first point of guidance to practitioners trying to decide whether, and to what extent, to adopt preventive and/or curative Future Adaptive Design strategies.

Extending product lifetimes is promoted as an important avenue to reducing environmental impacts; it allows spreading impacts from production over more use or function. However, extending product lifetimes does not always reduce environmental impact. Particularly with energy-consuming products, new products may be more efficient than older ones, and in these cases, product replacement could prove more environmentally beneficial than prolonging product use. Because the Future Adaptive Design framework does not specifically account for this, business developers and designers must be sure to review the ecological impacts associated with prolonging the product life of a specific product. However, to enact environmentally grounded adaptability would merely require a different data set. For example, by using lifecycle inventories also used for lifecycle assessments, practitioners can evaluate the ecological impacts associated with prolonging the product life of a specific product. However, to enact environmentally grounded adaptability would merely require a different data set. For example, by using lifecycle inventories also used for lifecycle assessments, practitioners can evaluate the ecological impacts associated with prolonging the product life of a specific product.

Financially grounded adaptability

- How much longevity is feasible from a financial perspective?
- How much longevity is desirable to meet a CE paradigm?
- Buy another type of product from supplier that saves cost over time e.g., that enables multi-layered modularisation or makes service faster, easier or more cost efficient?
- Initiate in own product innovation: weight the invested R&D cost vs product lifetime cost savings related to the innovation (when is the breakeven)?
- Evaluate potential cascade business after your products end of life when designing the product.
- Can external technology enable new types of products/product functions that can save cost?
- Reduced costs by increased used of renewable energy?

Environmentally grounded adaptability

- What is the potential to reduce environmental impacts associated with product longevity?
- What is the current ratio of use phase impacts versus non-use phase (production) impacts?
- How much longevity is feasible from an eco-sustainability perspective?
- Which parts represent the largest portions of the environmental impact related to production?
- Which parts or modules can be used for longer?
- Which parts need to be adapted and what burdens/investments would result based on design changes for longevity?
- In what ways could the use phase impacts be reduced?
As shown by Schwartz’s model of basic human values at right, not all customers have the same values. Some people can be characterized as more open to change, while others are more conservative. Transferring this logic to circular business models means anticipating that not all circular offerings will be attractive to every customer.

Consumer behaviour and the development of circular business models from the consumer perspective can be addressed with the Value Proposition Canvas approach. Here, customers are profiled according to three segments: their jobs (i.e. tasks they need to fulfill with the product in question) their pains (issues that need to be addressed) and their gains (advantages they can gain from the offer).

The scarce studies available on consumer acceptance of circular products show that consumers are concerned about the quality of reused goods, even if environmental benefits are evident (Kuah & Wang 2019). On the other hand, Lieder et al. (2018) found consumer interest in circular offers based on access and renting. Recent research also shows that certain levels of product circularity could increase customer’s willingness to pay (Boyer et al., 2021).

Example profiles for potential circular business model customers based on the four identified Schwartz human values are located in the Appendix.
Customer typology for product longevity, elevator in use since 1930

A house in central Gothenburg (on Eklandagatan) with ten apartments that was built in 1927. The building is family-owned by four siblings that have been owning the building together since the 1970s. The owner family describes that they always have been very careful in their approach to modernizations over the years, and carefully considered, and in many cases refused modernizations that they describe as the dominant "throw out everything" logic that they believe has deprived many buildings of that age their original architectural values associated. For example, they see modern windows, apartments doors, new floors, kitchens, etc., as elements that sanitize some of the charm of older buildings. However, being a trained architect with a focus on sustainable architecture has – according to one of the owners - made it easier to both observe and resist the dominant business logic in the building industry.

The elevator is - according to the owners - probably installed in 1930 and is still in use and certified according to the latest standards regarding electrical safety. However, such old elevators are described to have some safety and accessibility that do not meet current building codes.

Over the years the owner family describes that finding and keeping elevator service firms that are in line with the family's values of keeping instead of exchanging is a constant struggle, where "many have turned around already on entry". Over the years there have been very few failures and the uptime is described as very high as well as maintenance costs considered as low. The elevators are maintained every third month according to a service contract, and the owners only remember one major overhaul being done. Then the elevator engine was sent to be remanufactured.

Over the years there have been proposals from the tenants to modernize, and the residents are described as divided into two parts, where one group regularly chose to take the stairs due to claustrophobia and fear of technical failures, while the other half sees it as an important part in the soul of the building. The owner's family describes that they have no intentions to modernize if no major failure occurs.

To meet new electrical standards, some parts of the original control panel has been upgraded with new connectors and relays and a protective plexi-glass front protect against touching the panel.

The engine is original from the 1930ies and has only been overhauled on one occasion according to the owners. Documentation of service history is done manually and must be stored in the elevator machine room.
**Customer typology for product longevity, Tinkers**

Once upon a time, it was obvious to most people to be able to design and produce your products for everyday needs and to repair and modify those products. Although, as peoples needs, wants and professional guilds developed, products became ever more advanced, and tinkering often in combination with thrift has always been an important part of innovation and design, and are usually very little concerning about conventional thinking that might consider av product or component is obsolete. Instead obsolete is seen as an opportunity.

E.g the former carpenter Jehu Garcia, shifted to become a “YouTuber”. doing EV conversions of old vehicles and developing DIY products base on obsolete batteries among many other things. Jehu Garcia exemplifies a growing community of tinkers. That in today’s, social media landscape gather massive numbers of tinkers providing information and sharing eye-catching stories, as well as capturing values by selling components and DIY kits.

Others are less interested in sharing examples to a global community, like Anders, a retired Swedish forklift mechanic that converted his sailboat to electric propulsion using repurposed electric truck components, just to meet his vision of fossil-free living. However, he gladly shares his knowledge if being asked.

For those without knowledge, time, or a well-fitted garage. There are professional workshops offering retrofits of cars from ICE to BEV as EV –West in San Diego, which also produces modification kits for DIY. Similar trends are seen in the marine sector with a growing number of firms offering retrofit electrical engine and battery systems for DIY customers. Also, multinational automotive manufacturers such as Volkswagen have developed an EV platform aimed at retrofitting old beetles and busses from the 1960s.
Outlook
Promising examples of design for longevity by durability, flexibility & adaptability
Elevator as a service  M-USE

The Mitsubishi has in the Netherlands offered elevators as a service since 2017, under the name M-use, offering property owners a “worry free” access to elevators for a monthly fee. The planned for usable life is 50 years, in line with the planned for life of commercial buildings in the Netherlands. that is divided in two twenty years lease periods, plus a ten years optional period.

During the lease periods Mitsubishi claim the legal ownership of the elevator shaft and all elevator components. Service and upgrades are included with monthly maintenance stops every year. Customers can either pay a monthly fee without any upfront investments, or a down-payment that reduces the monthly fee. The M-use agreement is only available for new installations, where Mitsubishi can install the suitable components that meets customer requirements and extended longevity. The M-use elevators are monitored where malfunctions can be remediated before major failures occur, reducing costs, downtime and inconvenience for property owners and their tenants.

The project started in 2012, in combination with the building of the Park 2020 near Schiphol, with the aim to contribute to a circular economy by implementing C2C principles. Even if environmental benefits was in the forefront when starting, the financial benefits today is the main driver, and with over hundred installations, the M-use offering has been a success than contributes significantly the turnover.

In the M-Use, Mitsubishi have control over the whole value chain, including contacts with the end customers. However, compared to the dominant business logic for the dominant firms in the elevator industry, the M-use differs much regarding planned for product longevity and responsibility for the installed materials.

Circular business logic
- Customers buy access to the function worry free vertical transportaion
- Less bound capital for customers than buying elevators
- An objective to increase margins by lowering maintenance costs
- Stable revenue streams over a long time, creates a stable business
- MITSUBISHI owns the whole value chain
- Possibility to reach new customer segments that before chose low price competitors

Circular design logic
- Elevator components optimized for the planned for functional life
- Components designed to be exchangeable and reusable
- Health and health history of elevators are monitored by IoT
- Material passport keeping track of embedded materials

Potential for environmental reductions
- Extended longevity reduces CHG
- Cascading usage of components
- Material recycling is done when no usable life is left in components

References:
Based on personal interview with Mitsubishi during June 2020
https://www.mitsubishi-elevators.com/m-use/
Product longevity for smartphones, Fairphone

The telecom industry, with consumer electronics as smartphones represent one of the fastest growing waste streams of E-waste (ref). In Europe incentives to force manufacturers to prolong product life has been implemented in France, with was preceeded by law suits against Apple and Samsung for planned obsolescence. During 2021, German government are proposing that manufacturers should keep smartphones updatable for up to 7 years. The response from the branch organization is 2 years!

Fairphone is a Dutch company with ambitious goals to change the way smartphones are made throughout the whole value chain by designing long-lasting phones with “fair” and recyclable materials and reasonable working conditions for those working in the value chain. Fairphone started in 2010 with a campaign about conflict minerals. Since then, they have promoted transparency in their operations and marketing. By making their supply chain visible, Fairphone wants to initiate a discussion about where its consumer products come from, what raw materials it uses, and how the phones are made. Fairphone 2, released in 2016, was claimed to be the world’s first modular and fair smartphone and has been sold in many countries.

In 2019 Fairphone 3 was launched, which Fairphone was the worlds first smartphone that could be upgraded, by an exchangeable camera module, battery pack and speaker module with improved features. In Ifixit reparability score Fairphone 3 got 10/10. There is also a 3+ edition launched where existing customers could get the latest upgrades or new customers get the latest model, with the aim to keep main parts in existing phones for longer.

The camera module in model 3 was deliberately designed to allow exchange, and the physical interface with few connectors further make exchange feasible also for consumers themselves to exchange. However, as the chipset, the brain in the smartphones is not possible to upgrade Fairphone phase a challenge to keep phones up to date if. To further illustrate this the shift to the5G communication protocol, has required Fairphone to develop a new model; 4, that has the same objective for longevity but now in line with this new communication speed.

Circular business logic
- A competetive price point for smartphones
- Upgradeable modules instead of exchanging to a new product
- Low margins on spareparts, and exchange/repair instructions for free
- Building a strong community of dedicated users
- Stable revenue streams over a long time, creates a stable business
- Paying living vagues for subcontractors in value chain

Circular design logic
- Modular design
- Components designed to be exchangeable and reusable
- Material pasport keeping track of embedded materials
- Use of recycled minerals and plastics

Potential for environmental reductions
- Extended longevity reduces GHG
- Possibility for material recycling of exchanged components or phones
- Material recycling is the last
Exploring value preservation at Bang & Olufsen

Bang & Olufsen (B&O) has a long heritage regarding classic design and longevity. Many B&O products can last for decades, with products carried over through generations, and B&O has a strong user community with dedicated fans.

Many products have over the years become iconic with, high residual values on the second-hand market.

In 2020, when the company turned 95 an exploration about value preservation/improvement was carried out by buying back B&O Beogram 4000 turntables, designed by xx and manufactured and sold in the 1970ies. These products were then remanufactured by B&O and upgraded to the latest technical standards and visual qualities, together with documentation about the history. The remanufactured products were sold in a limited edition in 2020 at a good margin and have since increased even more in value on the second-hand market.

The project was initiated from B&O design by customer research about trends for sustainable, post-pandemic living, in combination with internal B&O roadmaps for increased circularity for tackling E-waste, etc. Together this formed the ground for the project’s two desired outcomes: 1: to challenge consumer behavior regarding product newness, and 2: to change actual customer behavior in practice by identifying willingness to pay for used B&O products.

The used products were disassembled, and the visual Aluminium surfaces were, refurbished, re-grinded, and anodized. New visual elements as a wooden frame and new finishes were added. The remanufacturing process was enabled by a high degree of modular design in the original product architecture, that also, in the 70ies had room for upgrades in form of a pre-amplifier, enabling upgraded connectivity to modern speakers.

Circular business logic
- High price with a promise of longevity
- High residual value of embedded components

Circular design logic
- Careful redesign updates based on the original design ideas about timelessness and upgradability
- Modular design, where components easily can be exchangeable and reused
- Components originally optimized for longevity

Potential for climate/environmental reductions
- Extended longevity has a significant potential to reduce GHG & E-waste
- Cascading usage of components saves energy & resources in the reman process

References:
Based on a personal interview with Bang & Olufsen in October 2021
Future proof design, the Beosound Level

The Beosound Level is a wireless, mobile speaker for streaming audio that was launched in 2021. The design team at B&O was inspired by their previous work with the Beogram 4000c and wanted to take further steps on their circular roadmap. The main design criteria for the Beosound Level was to create a modular future-proof product architecture, where some components are accessible for the users to exchange themselves, as the batteries and exterior panels that can change the visual appearance, while others are only available for repair shops. The main processor had been designed deliberately to run on 50% of its capacity to give room for future software upgrades that might require more capacity. The electronic components are specified for a life length of 10 years, and beyond. For most of the components, this will not be an issue. However, the communication module has deliberately been designed to be upgraded if new communications standards for streaming will be introduced over the usage time. Software upgrades will be done through the smartphone app that controls the speaker. To further support B&O's aims for longevity, Beosound Level comes with a 5-year warranty and software features that enable the products to be upgraded through the BEO app and with possibilities to do remote health checks. Spare parts will be available in repair kits. The sound can also be adapted to optimize the sound quality, based on how the speaker is positioned, and if moved between different locations. Enabled by embedded sensors.

Compared to other similar consumer electronic products the Beosound Levels, the potential for additional functional life will probably be much longer, as many electronic products with built-in batteries are affected by battery depreciation, and new technological standards being implemented driving them to be obsolete. From an OEM perspective, the availability of critical electronic components over time is also crucial to keep products in use, and previously B&O has done "last-time" buys of critical components to put in stock. However, in the case with the Beosound Level, B&O teamed up with some new subcontractors in the automotive industry that were used to supporting OEMs with spare parts for decades.

Moreover, the Beosound Level is the first Cradle to Cradle-certified consumer electronic product and is described as an in-depth learning process that gave the B&O development organization new knowledge regarding circular criteria and challenges in their existing value chain. In addition, it contributed to further developing the C2C certification process.

Circular business logic
- High price with a promise of longevity
- Embedded values in the produced product have a high residual value
- Prepared for new service offerings by a software roadmap
- Prepared for being offered as a service
- Long time agreement of suppliers of components and close collaboration with providers of operating systems (Apple & Google)

Circular design logic
- Components optimized for longevity
- Modular design and those with the highest risk of becoming prematurely obsolete are exchangeable
- Multiple connectivity standards, both wireless and by hardwire
- Health and health history can be remotely monitored
- Water protected according to (IP54)
- Use of recycled plastics, wood, and wool

Potential for climate/environmental reductions
- Extended longevity has a significant potential to reduce GHG & E-waste
- Cradle to cradle certification restrict usage of problematic substances and enable material recycling

References:
Based on a personal interview with Bang & Olufsen in October 2021
https://www.c2ccertified.org/products/scorecard/beosound-level-bang-olufsen-as
https://www.architecturaldigest.com/story/a-bang-olufsen-speaker-designed-to-take-on-the-e-waste-dilemma-launches
Vehicle design for longevity at riversimple

Riversimple is a startup company in the UK dedicated to changing the environmental footprint for passenger cars and to disrupt the traditional business and design logic compared to incumbent automotive OEMs. Their first model (the RASA) is being pilot tested (in 2021) with real customers and is a Fuel Cell electric vehicle (FCEV), built around a modular carbon composite skeleton with exchangeable exterior polymer panels. The planned for life length is 20 years and beyond. Main reasons for choosing hydrogen technology is to reduce the environmental impact from batteries, and the RASA model use supercapacitors instead of traditional Lion batteries, reducing weight and need of charging times. Compared with a Smart electric, the RASA only weighs 654 Kg, which is approx. 400 Kg less.

The design logic at Riversimple is described as being continuous where improvements to vehicles being produced will be made over time, e.g., exterior body shapes.

Riversimple's business logic is built around keeping ownership of and selling their vehicles as a service where customers pay a monthly fee for personal mobility including fuel, and harvest revenues over a long usage time. Using CFC was also a deliberate choice from an investment perspective as the traditional way to produce car bodies in pressed steel requires volumes of approx. 1 million units over a production life cycle of 7 years to reach break even. While, according to Riversimple, producing in CFC only requires a volume of 10,000 units.

Hugo Spowes, CEO of Riversimple started the company in 2007 based on his research about disruptive innovations in history, in combination with Amory Lovin’s research about the role of FC to mitigate climate emissions. The vision is to design the whole system instead of only focus on the vehicle itself. And Riversimple is building an innovation center to further drive circular initiatives.

Circular business logic
- Providing product as a service, customers pay for worry-free access including fuel
- Hypothesis that customers primarily care about reliability & predictable costs than the year model of vehicles
- High value materials to be used for longer
- Prepared for new service offerings by a software updates
- Distributed production

Circular design logic
- Components optimized for longevity 20+ years
- Modular design with exchangeable components
- Potential for environmental reductions
- Extended longevity offers potential for reducing GHG
- Circular materials?
- Lightweight
- FC technology and supercapacitors offers resource efficiency if renewable energy is used for Hydrogen production

“We are not interested in the end of the pipe solutions, we are interested in changing the system. We see that the Business Model affects everything and we try to design the whole system instead of only some of the pieces. In the incumbent industry everyone only optimizes their bit.” Hugo Spowes CEO of Riversimple
Cases studies from testing of CBMI/FAD framework
Together with Swedish OEMs of public signs & elevators
Circular signs at Accus

Background:
Accus is a sign manufacturer located in Malmö in Sweden that design develops and assembles both single signs and larger sign systems for private and public customers, in combination with assembly and maintenance services. A small portion of production is handled internally in Sweden while the major part is produced by subcontractors in Europe.

The business landscape
Accus’s main customers are commercial property owners and architects. Change of tenants in the property owners’ buildings, as expansions or closure, building renovations, or new building projects create needs for new graphic identity, renewal, or dismantling of existing signs. Advertising agencies have an important role in creating changes of graphical identities that often require new signs. The costs for signs can be from some thousand Sek., up to million Sek. for very large facade signs. The frequency of change can be from months to many decades depending on the type of business. There are two main sign types that Accus offer, sign systems where generic graphical content can be applied, and individual signs where the sign is closely connected to a specific brand and typographic. While the generic signs continuously can be upgraded when a change occurs, the specific signs will usually be scrapped after exchange. Accus is responsible to take back their signs according to ERP regulations but at the expense of the customer. Costs are the main criteria for purchasing, and usually, one-time signs are the default option.

Circular vision strategies at Accus
Accus CEO that is a part of the owner family has a bold vision for achieving as circular products as possible or “create visual communication with positive societal impact” and reducing Accus’s sustainability impact on society and ACCUs has in previous research projects explored CBM and implemented circular design. Results from these projects was a modular sign concept RE:sign designed for being able to med reused by only exchanging a printed film with the graphics. By this Accus claims that 98% of a RE:sign is reusable. Also, to use of recycled materials has been investigated. E.g with plans to use recycled Aluminium for frames. However, Accus have difficulties to source recycled Aluminium, and the hardened glass fronts are not possible to recycle. In Accus plastic sign products, Acrylic from recycled ingredients is implemented as standard.

A circular business model for signs
Accus’s vision is to take control over the sign’s lifecycle by providing it as a service by a subscription model, combined with maintenance and material recycling of components that became obsolete. This CBM was developed and tested on a number of pilot customers, although with challenges to get customer acceptance for a subscription instead of buying and owning signs traditionally.

Products related business risks in a CBM
The function of signs is to communicate the customer’s brand identity and position. Risks for premature obsolescence could be due to physical damages (it is not uncommon that signs are taken down by trucks turning), or fading, missing backlight. Other technical risks I related to wear of electronic drivers and LEDs, as they have a life expectancy of about 7 years (driver) x years (led). There is also a technical development with e.g digital signs as OLED on its way out on the market that offer the advantage of the changeability of the graphical content remotely.

Functional changes could be due to new dimensions for signs when buildings are being renovated and e.g., an architect specifies dimensional criteria for the signs, etc. Social changes, as new customer behavior could be about how shop owners consider existing signs and might need alternative signs for e.g. pop-up stores that are an emerging trend. Changes in legislation seldom risk signs to be obsolete, with the exception of large facade signs that might risk detaching from buildings in heavy winds.

References:
Based on personal interviews on workshops with Accus during 2019-2021
OLED technology see e.g. https://www.lg.com/global/business/oled-signage
Circular signs and product adaptability

The RE:sign’s potential for longevity
The product architecture is built up of a supportive frame of welded Aluminium profiles, sheets of hardened glass back and fronts, an exchangeable film presenting the customer’s identity. The glass covers are held in place by metal clips that are screwed to the frame. Inside is LEDs and, wiring mounted to the frame, together with an electronic -driver. The sign is mounted to the façade with screws and connected to the grid. Depending on the height of the sign a, sky-lift could be required for cleaning or to exchange the graphical films. The planned life expectancy is 25 years, followed by a possibility to remanufacture to new like condition. However, the dimensions are fixed and the sign is only available in a fixed rectangular or circular shape.

Lifecycle Service Planning.
The components in the RE signs architecture have a different life expectancy. In a planned-for scenario, cleaning is done regularly, exchanging the sign films depending on changes at the customer. The aluminium frame and glass fronts are planned to last 25y. Led and drivers have a life expectancy of 6-8 years and have to be exchanged 2 times.

Multilayered modularity and interoperability
The PA modular components are easily separable and could be divided into multilayered categories. According to figure3. Led’s, electronic drivers and interfaces are standard components.

Continuous service innovation
Today accus offer service agreements as cleaning and exchange of graphic films, and there are also plans to offer the possibility to automatically dim the sign on nights to save energy and reduce light pollution.

Cascading customer loops
Accus, has the ambition to reuse harvested complete Re:signs and if not viable, harvest values from exchanged parts. Here, metals and glass have a high value while plastics and electronics have low residual values. Here accus are experimenting with various solutions as repurposing materials into new unique signs as in figure 1

Financially grounded adaptivity
Accus claim that the Re:sign is not more expensive than their other signs and that the modular product design reduces labor time when exchanging graphical films, which further increases the potential for profitability when selling the Re: sign as a service.

Suggested design improvements
The Re:sign has many strengths for longevity, such as a modular architecture with exchangeable films, a simple design with high-quality materials as anodized aluminum, and glass with predictable wear. However, the process of exchanging the graphical films today requires dismantling the sign and returning it to Accus workshop. This leads to increased costs, especially if signs are placed at heights that require skylights. Here, design improvements that simplify film exchange at the customer’s location could be considered.

Summary and discussion
Accus ambitious circular vision and systematic work have resulted in improved organizational capabilities for CBMI and circular design. However due to a traditional purchase logic among customers, purchasing signs as a subscription seems to be a current barrier. Eventually, the buying logic in the property branch might change towards more focus on longevity for buildings and various building components. Although, even if selling products as a function by a subscription model has been argued as being the most circular solution by the CE research community, a CBM built around long-lasting products, sold traditionally but with an upgrade and buyback agreements can still lead to realizing the embedded circular potential. However, in such a CBM there is a risk over time that the original circular ideas of the product are forgotten as time goes by, and management and staff at the customers change, and keeping the customer contact and product history will be crucial to enable longevity.
Circular signs and the potential for environmental impact reductions

A large portion of a sign can be reused if the graphic can be changed, and energy use to light the sign can be reduced. In the end, large reductions in greenhouse gases can be achieved.

Figure 1: In Accus modular RE:sign only a thin film is replaced if the sign needs to be updated with a new graphical content. Thus only 2 weight percent of embedded materials need to be exchanged when changing signs.

Figure 2: The effect usage in the RE:sign is only 20-30 w by using LED. To further reduce the impact over the lifecycle accus investigates how signs could be dimmed to 30% of light capacity during nights to reduce energy usage even more.

Figure 3: LCA conducted by Accus with 4 scenarios, 3 linear with various materials and one circular scenario. Scenario 4 (Resign) yields reductions of over 65% compared to the standard outcome (linear).
Elevator as a service for as long as the building itself

Background:
The global elevator industry is dominated by four main firms, Otis, Schindler, TK Elevator, Kone. The rest of the market is shared between numerous smaller actors producing elevator components, installing, replacing, and doing maintenance. Competition for new elevator contracts is fierce, with usually very low margins on new sales, and with service contracts, where service and expensive exchange of components creates the main revenue streams for the OEMs. The dominant business logic among most of the larger OEMs is described as focusing on new installations and full replacements. I.e that old elevators are completely removed, existing materials scrapped, and a new elevator is installed. The dominant design logic is described as having a focus on efficient production, e.g. reducing modularization in favor of combining components, and control systems that are locked to specific OEMs after installation, with an optimized lifetime a bit over the set warranty intervals for components. The expected life length for elevators installed today ranges from 20-25 years depending on intense usage and is a decrease from elevators installed from the 60s, which had a life expectancy of about 40 years and more. However, elevators can have a very long-life length and there are examples of elevators in Sweden installed in the 1930s that still operate in the 2020s. However, with described difficulties for property owners to find service firms that are willing to engage in keeping such old elevators up to date, as most service firms consider them to be obsolete and to be exchanged with new components. On p. x such an old elevator example is illustrated.

Hydroware is a Swedish manufacturing firm that since the 90s has developed and produced drive and control systems for elevators. Hydroware’s core business since started 1998 has been to modernize existing elevators, by a modernization kit. Hydroware’s major product segment is for hydraulic elevators that are most suitable for buildings up to 6-7 floors, with advantages as, less needed space, faster installation time, compared to the most common traction elevator installations.

Circular vision strategies at Hydroware
Hydroware’s founder and majority owner had over the years seen how the main business logic in the elevator industry increasingly had resulted in many valuable components and materials just being scrapped prematurely. At the same time, the debate in the industry mainly had a sole focus on reducing energy consumption during the usage phase, excluding the impact from production and end-of-life stages. A hypothesis if extending longevity was a route that could save both resources and money started to grow and to be debated in Hydroware’s top management. To explore this hypothesis of extended longevity further an LCA was conducted in 2015 showing significant potential for CO2 reductions by extending elevator usage time from 20 to 80 years. Over the years customers had responded positively to the modernization offer, and Hydroware saw an opportunity to go on step further in exploring if a functional sale offer could be a further step towards their vision; formulated as “vertical transportation that could last as long as the building itself”. That for many buildings can be much more than eighty years. Also, exploration of other circular activities as harvest exchanged components to remanufacture, more energy-efficient usage, predictive maintenance and material recycling started to emerge.

Potential for longevity for current hydraulic elevator design
The risks for premature obsolescence in current hydraulic elevator architecture are mostly related to the moving parts as the main hydraulic cylinder, valves, to together with doors, the car interior and landing panels (buttons and indicators). Also, electronics and printed circuit boards have a limited lifetime. Occasionally, thunder and flooding’s can risk to create more severe technical failures. Furthermore, visual wear of interior elements as surface colors, lightning quality, etc. poses the most aesthetical risks. The risk for functional obsolescence is mostly related to, lack of regular maintenance, introduction or phasing out of new standards. For example, as the 2g and 3g nets currently being phased out in Sweden, this will require an exchange of 2g, 3g emergency phones. Such risks are associated with social obsolescence, as well as the implementation of new regulations for accessibility and safety that for old elevator installations can be difficult to meet.
Hydraulic Elevators and Product adaptability

Lifecycle Service Planning.
The components in the complete elevator installation have different life expectancies and maintenance needs. Components most sensitive to errors and related to elevator downtime are elevator doors, where gravel and small objects can result in doors malfunctions. Elevators usually are maintained regularly with the exchange of consumables as e.g filters and wear components. Yearly safety certification is also required, and without regular maintenance, elevators risk getting driving bans.

Multilayered modularity and interoperability
Most elevator components are modular and easily accessible. Exceptions are printed circuit boards (PCBs) in the elevator controller and BUS system, where the exchangeability of some components is limited. In the elevator industry drive and control systems that are locked to a specific OEM are common, creating barriers for maintenance personal doing troubleshooting and increased costs for property owners. Hydroware instead uses the Can open standard that enables interoperability for electronic components as control buttons, sensors, etc. Also, the elevator steering, and control system will be compatible with DC input to e.g. battery backups and solar panels, to enable a coming increase of local renewable energy systems.

Continuous service innovation
The rapid development of IoT technologies has enabled Hydroware to implement health monitoring functionality for the elevators that enable predictive maintenance. Also, service and health history can be stored and accessed, which open up for new service development based on actual individual elevator usage.

Cascading customer loops
Hydroware has the ambition to reuse elevator components and if not viable, harvest values from exchanged parts. Here foremost the electric motor, the main hydraulic cylinder, and drive electronics has the highest residual values. Also repurposing of used EV batteries is being explored as a way to offer new functionality in smart buildings as to help reduce electric peaks.

Financially grounded adaptivity
Based on the FAD assessment a range of more durable components has been considered, where especially high-quality doors have been considered as removing potential downtime, in combination with regular cleaning schemes.

Also reconditioning or remanufacturing of hydraulic components and PCBs will be explored as ways to reduce cost.

Suggested design improvements
The main suggestions for improvements are regarding, increased focus on specifying components that Hydroware is not manufacturing today to be in line with the extended lifetime, as e.g more wear resistant surface treatments on moving hydraulic parts. As well as choosing door types where the surfaces can easily be refurbished to reduce visual wear. Also, more modular and upgradable PCBs in the elevator controller and BUS system have been identified to better protect the electronics against peak currents, or other damages.

Summary and discussion
Hydroware’s vision of providing an elevator as a service based on long-lasting elevator components is from a product design perspective doable based on the current product architecture. However, further in-depth explorations of identified components are needed for suggesting detailed redesign activities that can further reduce the identified risk for premature obsolescence, and thus contribute to increased profitability and realize the planned for longevity in the CBM.
Conceptual proposal for an Adaptable elevator

The following section is presenting a fictive scenario of an elevator as a service from a customer and user perspective. Although partly being based on real customer data during the research project, it does not represent an actual business offering.

Background
The housing cooperative “High Five” includes five houses in Bagarmossen south of Stockholm City. The houses built in the early 2000s have in total ten elevators.

Over the years elevators are the area that has created many headaches for the different members of the boards. As the board members usually exchange after 2 to 5 years, documentation and keeping the information for the elevators over the years is challenging. Usually, the information about service and repairs is entered manually in a logbook, that is stored in each elevator’s machine room. The current elevator, which was exchanged at the end of the 1990ies, came with a 5-year service agreement that included all maintenance and exchange of broken components.

However, when this agreement ended, problems started to emerge, as well as increased costs for service and exchange of components. As each resident had access to the phone number of the elevator service firm, many faults were reported in parallel, and the board members had difficulties understanding the many invoices for the different visits and repairs. It could be that some residents heard disturbing sounds or experienced doors or buttons not working etc. Especially, buttons became an increasing cost post, as these elevators were looked to a specifics manufacturers control system, and accordantly represented high prices as spare parts. Eventually, the board decided to make an action plan for the elevators and an elevator consultant was assigned. The consultant report concluded that all ten elevators most likely had to be replaced within five years, with an expected cost of 1 million Sek./each.

As the housing cooperative already had made several major investments due to earlier identified construction fraud, and upgrades as solar panels and charge points, financing elevators for 10 million would considerably increase the monthly fee, as the bank only offered an in-Banco loan with a high-interest rate.

When the plan was proposed at the Annual general meeting, many residents objected and the suggestion for new elevators was voted down, and the board was forced to look for alternatives. After some search, they came across one elevator OEM offering elevator as a service.

Elevator as a service offering from a customer perspective
Initially, the board members were hesitant about this offer as it was difficult to understand in detail, and there had been a tradition to purchase all new equipment, but eventually, the proposal was put forward on an extra general meeting and was accepted by the members. Many members felt that the idea of using the elevator as long as the building would stand made sense as it would save costs and reduce environmental impact.

The housing cooperative now pays for access to the elevator in contract periods of 10 years at a time, with an option for renewal for a new 10 years period during the 9th year. Payment is based on a monthly fee which included and agreed uptime but excludes electricity. The monthly fee is constant for the first 10 year (except for an increase in the “stibor” interest rate) and then decreases over each following 10 year period. There is no defined limit for the subscription time, with more than 80 years as a vision.

Each elevator’s health and health history is monitored remotely, where errors that could lead to failures are identified at an early stage. Here regular cleaning of the car and especially the doors sills, carried out by the residents’ taking turns, both reduce risks for door malfunction and save costs. The contract allows for one major yearly inspection where one elevator at a time is down during a whole day.
Conceptual proposal for an future adaptable elevator

After every 20 years, the elevator is going through a major overhaul, where the elevator car is updated, doors repainted, and the drive and control system are overviewed and required parts are reconditioned. Remanufactured components are used where possible. Over years new service content has been included based on needs identified by usage patterns and described needs. New functions as remote driving up, light experience "Friday disco" and a program to incentivize residents to take the stairs resulted in both stronger attachments and reduced electricity bills.

Now some residents see it as a sport to use the elevator as little as possible, giving more access to the many elderly residents, being dependent on elevators for their daily mobility. Also, used EV batteries have been installed in the elevator machine rooms, helping reduce energy peaks, at peak loads over the clock. Together with solar panels, this system also enables charging of Evs, as well as keeping the elevator up if power failures occur, with remained lightning.

Now after almost nine years of the service, the board spends very little concern over their elevators, they just run, and problems are usually solved without major downtime. They also get one invoice, have a personal contact person at the elevator company that works very well.

An additional benefit has also been that as the board members in the housing cooperative are being exchanged, the carry-over of information regarding the elevators has been much easier than before as all history is stored digitally at the service provider with a customer account. Before collecting information about service history and repairs and planning for new service for the elevators was usually being a time-consuming, and frustrating task for the board members.

Over the year, there have been two major issues, once the basement was flooded, and once building was hit by lightning. However, due to the design with sealed components and circuit board with lightning protection the elevators were up and running after two days, and the extra costs were covered by the residential insurance. Also, power failures have been more frequent over the last years and the possibility to run the elevators on batteries has been appreciated by the elderly residents. Over the years, some members have raised concern that the costs might be higher than if buying new elevators, but as the board can show the TCO calculations for the extended longevity, this will usually end this discussion. Moreover, as many residents are being concerned about saving resources and reducing climate impact there is now a broad acceptance for the elevator as a service agreement in the housing cooperative.

By also working with incentives to the residents to reduce the usage of elevators there has been a win-win regarding reduced energy usage, costs for maintenance and overhauls, as well as the availability for those residents being dependent on the elevator, i.e elderly and disabled.

References:
Based on personal interviews on workshops with Hydroware, property owners, board members and residents in housing cooperatives, elevator service firms and consultants during 2019-2021
Global "Elevator and Escalator Market (2021)"
Elevator longevity and energy/resource efficiency

Analysis was done with existing LCAs to estimate potentials. Main assessments include identification of important modules and assessing use phase potentials. Results show potential of up to 55% reductions in environmental impact, with the existing practice of modernization representing 38%.

Potential related to production impacts: Determining the potential to extend product life (Use vs Non-use impacts): Impacts (including CO2 emissions) related to production of the equipment (non-use) represent a majority of the impacts resulting from 80 years of elevator function (figure below). This means that extending the use phase (instead of replacing elevators every 20 years) can mean a relatively large reduction in total environmental impact.

Key parts: Which modules represent the largest production impacts? (Hotspot analysis): The shaft material and car modules represent more than a combined 50% of the impact, with the controller, machine and door modules representing most of the remainder. Extending lives of the most impactful modules will yield the most benefit.

Estimate potential for 6 possible outcomes: Results are presented in the unit used by LCA results at hand, Recipe endpoint, a system that allows for aggregating 16 major impact categories into one measure. Recipe is used because ample breakdowns by impact categories were not available. However, the limited results for global warming potential (presented for each phase, but not for modules, nor for other analyses, like energy recovery) very strongly correlate to global warming potential results for the elevator. Results show a range of potential reductions of 38-55% compared to the base case (4 new elevators). This includes energy reductions during the use phase of up to 35%, which results in a reduction of 40,000 kwh for an elevator used in moderate use scenario for the 80-year period. Other outcomes are generated assuming different combination of module life extension resulting from modernization and reductions in use phase impacts, resulting from reduced trips and/or energy recovery (details on next page).
Elevator longevity and energy/resource efficiency (more explanation)

Analysis was done with existing LCAs to estimate potentials related to both non-use and use impacts. More reasoning and assumptions are found here.

Estimation related to non-use (production) impacts:
Estimate potentials of modernization which allows for reuse of many parts. The table below shows an estimate of how many modules that would be needed to deliver 80 years of service if an elevator would be installed and then modernized every 20 years. Without modernization, replacements of elevators would require 4.0 of each module.

<table>
<thead>
<tr>
<th>Cylinder</th>
<th>4,0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors</td>
<td>2,0</td>
</tr>
<tr>
<td>Car</td>
<td>1,3</td>
</tr>
<tr>
<td>Machine</td>
<td>1,3</td>
</tr>
<tr>
<td>Shaft material</td>
<td>1,3</td>
</tr>
<tr>
<td>Controller</td>
<td>4,0</td>
</tr>
</tbody>
</table>

Estimation of potential to reduce use phase emissions.
Three ways of reducing use phase impacts were identified: (1) reducing use/ reducing trips, (2) reducing standby energy and (3) energy recovery.
First, reducing trips taken could be achieved by nudging building residents to take the stairs instead. This measure presents the added benefit of reducing wear and tear and increasing part longevity and is especially feasible for the primary niche of the hydraulic elevator, low-rise buildings not exceeding 10 floors. Adding messaging or symbols to nudge residents towards the stairs or even including pay-per-trip incentives to the payment logic were discussed as ways to achieve this during business model innovation.
Secondly, energy used during standby represents a large part of total energy use. In settings with low-frequency use, standby energy represents a majority of energy demand. In settings with more frequent use, the energy used during trips represents the majority. Naturally, incentives focused on reducing trips would best target high frequency use settings. While reducing stand-by energy is a natural target, no immediate solution was identified. That being said, if energy would be recovered and stored (such as in battery storage) that energy could at least be used to cover some of the standby demand. Energy storage could also offer emergency power and could reduce peak loads, two features that would be attractive to some customers. However, we don’t estimate the potential of such a solution.
Here, for purposes of estimating total potential of FAD outcomes, we use a previous LCA, which estimated that energy demand could be reduced by around 25%. In addition, we assume 25% reduction of trips in the scenarios shown in the chart below. We assume this to yield a 12.5% total energy reduction due to an at least equal energy demand from standby energy. Results are presented in the unit used by the LCA results at hand, Recipe endpoint, a system that allows for aggregating 16 major impact categories into one measure. Recipe is used because ample breakdowns by impact categories were not available. However, the limited results for global warming potential (presented for each phase, but not for modules, nor for other analyses, like energy recovery) very strongly correlate to global warming potential results for the elevator.
Summary
Summary

The Future Adaptive Design framework provides a common language for business developers and designers to explore how profitability and product longevity can go hand-in-hand in CBMs. This could help facilitate internal company discussions related to the costs and benefits of designing products for increased longevity.

Conclusions are that testing the framework/working methods simplifies the work of identifying, prioritizing, and discussing current products' strengths and weaknesses regarding durability, flexibility, and upgradeability, which is transferable to cost calculations over an extended period of use. As well as developing improvement proposals that can identify business risks for premature outdating. Challenges are primarily organizational. For example, the right skills have to be acquired early on, a set vision needs to be maintained, and a high work rate must be maintained when developing and testing a CBM towards potential customers. In the case of lifts as a service, Swedish legislation on ownership of fixed installations in buildings is also an obstacle.

Furthermore, we see a growing number of manufacturing firms, designers, and large and small customers that start to question the dominant linear business logic, and have an urge to design for longer product life, or source such products with predictable life cycle costs, with worry-free usage. We present some of those we think are promising but there are many more examples on their way out in society.

Some of them struggle with internal barriers in large complex organizations. Others, just start working and stick to their vision. We hope that our research can inspire those that are curious about what it could be for them, as well as spurring those firms already have circular business models built around last products up and running and what to improve them even further.
Suggestions for further research
Suggestions for further research

The framework and strategies are currently being applied and tested in practice by the authors with business and product developers from manufacturing firms in the automotive, elevator and the material handling industries. However, as this research is ongoing, understanding of their effectiveness in practice is limited.

Further research may identify limits to the extent that companies can apply Future Adaptive Design in practice. Company position in the value chain may affect its ability to implement Future Adaptive Design. If companies have limited control over hardware and software specifications, applying FAD strategies such as “Multilayer Modularity and Interoperability” or “Continuous Service Innovation” may be more challenging as compared to companies having complete control. For example, as a relatively small mobile phone manufacturer, Fairphone is squeezed between large subcontractors of electronics and operating systems who have greater influence on component lifetimes and compatibility between different versions of software applications. Thus, Fairphone subcontractors dictate the “death date” for the hardware, for example, if the production of a chipset model is stopped or if a newer version of Android no longer supports the previous chipset. The presented Future Adaptive Design framework does not currently provide ways to address this, but understanding such limitations and associated risks is necessary and should be further investigated.

The study has also not investigated company interest in Future Adaptive Design approaches. There may be limits to the extent companies are willing to apply Future Adaptive Design in practice as not all companies may have interest in CBMs. This might particularly be the case in developing nations where companies have been documented to be less engaged with environmental responsibility [81]. Still, Future Adaptive Design may even be attractive to such firms if it is a way to increase market competitiveness, save costs, or increase profits.

Moreover, another presumed limitation of the research is its lack of applicability to bioeconomy applications such as agricultural waste. This is because most of the strategies in literature that the current framework draws from are aimed at designing durable goods. Thus, future research could focus on the applicability and attractiveness of Future Adaptive Design, both to firms in developed and developing countries – and in different industry sectors.

Another area that could prevent implementation of FAD is for products categories that requires certification within specific types as vehicles. In Europe the WLTP directive specifies

Furthermore, a better understanding of customer requirements can help in designing long-lasting and adaptable products. Customer incentives and actual behavior with adaptable products needs to be further explored. E.g. what if customers do not care if some parts in a product are 20 years old and others 2 months old? What if some components have been used in several other products before? Will this be acceptable as long as safety and functionality are met? How often would a customer want to change certain components if that was possible? Or for how long time will it be interesting for a customer to keep a specific product? Must upgrades be visible to be accepted?

Summery of suggested areas for further research

- The role of certification as a barrier for adaptable products. The possibility to upgrade vehicles with components that change original specifications is limited in EU
- How open standards can enable upgradability e.g. open hardware and software
- The size and position in the value chain and possibilities to implement FAD. E.g. how can SMEs that are dependent on large subcontractors secure access of older components and
- Interoperability with new softwares?
- Incentives for adopting CBMs and FAD in developing countries
- Customers acceptance for keeping and using FA products
Appendix
1. NOW

- Exploring organizational capabilities
- Developing a vision for "absolute" circularity

2. DISCOVER

- Defining a vision for a desired future state & the gap in relation to the vision
- Exploring organizational challenges
- Setting up a dedicated team for circular business model innovation (CBMI)

3. DEFINE

- Slowing resource flows
- Narrowing resource loops
- Closing resource loops
- Setting a vision for "absolute" circularity
- Explore & develop value proposition(s), hypothesis & BMs
- Explore the risks for premature product obsolescence and mitigating activities

4. DEVELOP

- Testing of CMBO Prototype
- Financial and environmental grounded adaptability
- Developing product and service concepts
- Decide on circular product & service concepts

5. DELIVER

- A parallel kneading of the CBM and supporting products and services, without losing sight of the vision
- A parallel kneading of the CBM and supporting products and services, without losing sight of the vision
- Developing the circular business model
- Testing and validating the circular business model
Steps 2-4 in the CBMI process:

1. Setting a Circular Vision
   1.1 What is a vision that by circular principles can lead us to profitable reduce our impact in line with set targets in time? (FFF)

2. CBM & Design
   2.1 Develop VP/CBM
   2.2 Exploring product related business risks
   2.3 Test & evaluation (pilot test with customers)
   2.4 Validation
      > Can the potential for profitable, climate/enviro reductions be realized in this CBM with these products/services used?
      > What has to change in the organization and value chain?

3. Action plan CBM

Exploring product related risks

- Setting level of analysis
  - Choosing what level to analyze, e.g. an eco-system, product (product) system, or a component

- FAD risk assessment
  - Exploring risks for premature product obsolescence (aesthetical, functional, technical & social drivers)
  - Sorting between risk mitigating activities

- FAD as is assessment
  - Analysis of product ‘as is’ and possible short term mitigating activities
  - Comparing prioritized risks with ‘as is’ FAD capabilities
  - Exploring what could be short term mitigating activities not requiring redesign

- Circular assessment
  - Exploring what circular strategies are already met today in current design

- LCA hotspots
  - Identify components with a high/low ECO sustainability impact

- Cost hotspots
  - Identify components with high/low cost

- Explore further FAD improvements
  - Focus on finding improvements with help of the FAD framework

Financial and environmental grounded adaptability

- Explore cost/benefits by suggested improvements

Documentation

- Documentation of all steps

Action plan FAD

- Decide what could be improved by short, medium vs long term solutions

Development of CBM

- Exploring and finding mitigating strategies for product related business risks

Testing and validation
Start with defining a future desired absolute circular state for our firm

What is our vision for capturing values by extended product longevity by applying circular principles

What do we have to achieve to meet principles for a future (absolute) circular economy?

Principles for backcasting adapted from Holmberg & Robert, (2000), Circular principles adapted adapted from Konietzko et al., (2020); Bocken et al., (2016)

Today’s (problematic) situation

How does our baseline Look like? What is our current durability, flexibility & adaptability and climate/environmental impact for product that we produce or buy?

SETTING A CIRCULAR VISION FOR LONGEVITY
Identifying risk for premature obsolescence

<table>
<thead>
<tr>
<th>RISK for premature obsolescence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>How will changing fashions and styles impact your products and services over time?</strong></td>
</tr>
<tr>
<td>List all possible future events (occurrences) related to aesthetics that could cause the product to become prematurely obsolete.</td>
</tr>
<tr>
<td><strong>What might need to be repaired, and what technologies or replaced in the given timescale?</strong></td>
</tr>
<tr>
<td>List all possible future events (occurrences) related to technical aspects that could cause the product to become prematurely obsolete.</td>
</tr>
<tr>
<td><strong>What changing customer needs and technologies might occur in the given timescale?</strong></td>
</tr>
<tr>
<td>List all possible future events (occurrences) related to customer's functional requirements that could cause the product to become prematurely obsolete.</td>
</tr>
<tr>
<td><strong>What societal trends or new legislation may occur in the given timescale?</strong></td>
</tr>
<tr>
<td>List all possible future events (occurrences) related to societal trends that could cause the product to become prematurely obsolete.</td>
</tr>
</tbody>
</table>
Premature obsolescence timeline

- Aesthetical risks
- Technical risks
- Functional risks
- Social risks
Risk assessment

Risk Wall

**High business impact**
> List possible failures, accidents that can result in severe personal injuries, damage/lost products that could be solved with insurances, but to a very high premium

**Low business risks:**
List risks for unexpected costs that are judged to be in line with made cost assumptions in the CBM

**Medium business impact:**
List manageable risks that could be accounted for by including a risk premium in the CBM

**Unacceptable business risks:**
> List possible risks that can result in severe personal injuries and damage/lost products beyond what could be solved with insurances

**Actions:**
- Risks that must be addressed before launching the CBM
- No actions to be taken before launch.
- Full stop until these risks are explored further
- Risks that are known and will be under observation after launching the CBM
A screening tool for Future Adaptive Design

This tool helps you to assess how well your existing design can resist obsolescence. It also helps you to identify opportunities to make your design more adaptable to future uncertainties in order to reduce the risks of premature obsolescence.

A tool for screening how well your design can resist obsolescence

The tool consists of a set of checklists that highlights a number of key issues related to the four buildings blocks and the four drivers of premature obsolescence. You can use the checklists to discuss relevant aspects and assess your design. In addition, the tool provides a summery of your assessment to facilitate an overall analysis of how you can make your design more adaptable to future uncertainties in order to reduce the risks of premature obsolescence.

An Excel template will be available from November 2021 at: https://www.ri.se/en/what-we-do/expertises/future-adaptive-design-for-a-circular-economy
• Combining exercise and transportation
• Being a good citizen
• Public transportation that works efficiently
• Recreation in nature
• Supporting social initiatives
• Sharing things
• Eco performance

Gains

Pains
• Having a car you hardly use
• Feeling forced to own a car
• Car ownership & maintenance
• Paying for street parking

Customer Jobs
• Getting to places practically & sustainably
• Drive children to activities
• To transport things for work and bought on blocket.se
• Visit friends and nature
• Drive to sailboat

Mr. Self-Transcendence

Living location: Bromma
Occupation: KTH Lecturer
Education Level: PhD

completed profile
Sir Self-Enhancement

Living location: Östermalm
Occupation: Banker
Education Level: Masters

Gains
- Recognition by friends, colleagues, and strangers
- Premium brand/posh car
- Enhanced status

Pains
- Looking cheap
- Lack of control
- Forced into new travel behaviors
- Forced to improvise
- Arrive too late
- Sharing a car
- Environmental taxes

Customer Jobs
- Looking good & important
- Feel powerful & successful
- Social status
- Getting from point A to point B as quick as possible
- Commute to work
- Look good in company parking garage
- Take client calls enroute

completed profile
Ideation: FAD improvements

Multi-layered Modularity & Interoperability (MMI)

- How could this component/system/product become more layered based modular?
- How could this component/system/product become more open for software updates?
- How could this component/system/product become more interoperable?

Continuous Service Innovation (CSI)

- How could this component/system be continuously improved?
- How could this component/system be continuously enhanced?
- How could this component/system be continuously marketed?

Lifecycle Service Planning (LSP)

- How could a component/system be optimized over the lifecycle?
- How could major upgrades be made?
- What new technologies could be integrated?

Cascading Customer Usage (CCU)

- How could embedded values be captured for exchanged components by cascading customer usage?
Multilayer Modularization ideation support card

This principle addresses the issue of how to create a product architecture (PA) that can enable the interchangeability of the embedded components by allowing for systematic and cost-effective upgrades.

The idea is to achieve a PA where change can be made in one layer without affecting other layers. In analogy with the human body the layers are structured in:

- **Skeleton**: Represents the internal structure in the (PA), i.e. by endo or exoskeleton, providing a stable structure. For products as vehicles, the personal car body (the unibody) represents a large amount of the product weight, but if produced in metals, the unibody represents rather low economic values, given the total product cost. However, the material value should be kept unaffected even when organs and skins become obsolete.

- **Organs**: Represent components or sub-system in the (PA) that executes a specific function, as a movement in space, storage, and distribution of information, energy, etc. Organs become mainly technically and functionally obsolete. Make upgradeable and re-fabricable to minimize aging costs.

- **Metabolism**: Represents the energy and consumables that due to the PA inevitably are needed to fulfill the overall functionality and intended performance of the overall product system. E.g. in an internal combustion engine, petrol and diesel fuels can be used, but are not interchangeable in the same configuration of the PA. Furthermore, an ICE is designed for continuously changing consumables like oil, filters, gaskets, etc, to keep the organs in the product system as specified.

- **Skin**: Represents the physical surfaces that customers and users see, feel, and meet through product usage and service touch services. I.e. exterior and interior product components that are visible or tactile to the user.

- **DNA**: Represents values to be preserved and passed on over time such as numerical data and drawings, brand values, information about material content, product life history.

A layered-based product architecture:

By dividing a product architecture into separable layers according to their necessary functions based on the human body metaphor, designers can reduce complexity about how to design for durability, flexibility, and adaptability.
Sustainable Business is a group of researchers within RISE, that since 2013 has systematically worked with knowledge building in Circular Economy with a focus on circular business models, business model innovation, business ecosystem measurability, product-related business risks, environment, and climate benefits, etc. We believe that more resource-productive circular business models can accelerate the transition in society to radically reduce the climate and environmental impact.

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