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Design Circular Framework Setting - Composite recovery design solutions in the automotive industry

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This CEN Workshop Agreement (CWA 17806:2021) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid prototyping to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations – Part 2. It was approved by a Workshop of representatives of interested parties on 2021-01-12, the constitution of which was supported by CEN following the public call for participation made on 2020-11-24. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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The following organizations and individuals developed and approved this CEN Workshop Agreement:

- Universitat Politècnica de Catalunya, Barcelona Tech (UPC), Spain, Mr Luis Romeral Martínez (Chairperson), Mrs Eva María Urbano González, Mr Victor Martínez Viol
- Centro Tecnológico ITENE, Spain, Mr Sergio Güerri (Vice Chairman and CWA draft leadership)
- UNE, Spain, Mrs Isabel Linares (Secretary)
- BELLVER, Spain, Mrs Irina Ferreres
- AIDIMME, Spain, Mrs Maria Alicia Pérez Torres; Mrs Ana María Hurtado Ruíz
- ANAIP, Spain, Mrs María del Carmen del Amo
- European Recycling Industries Confederation (EuRIC), Belgium, Mr Alejandro Navazas
- Innovation Plasturgie Composites (IPC). France, Mrs Sandrine Lebigre
- ECOS, Belgium, Mrs Fanny Rateau
- Kawasaki Motor Europe N.V, The Netherlands, Mr Elmo Kaiser, Mr Martin Buitelaar
- MAIER, Spain, Mr Mario Ordóñez
- Oakdene Hollins, United Kingdom, Mrs Olivia Bertham, Mrs Katerina Michailidou

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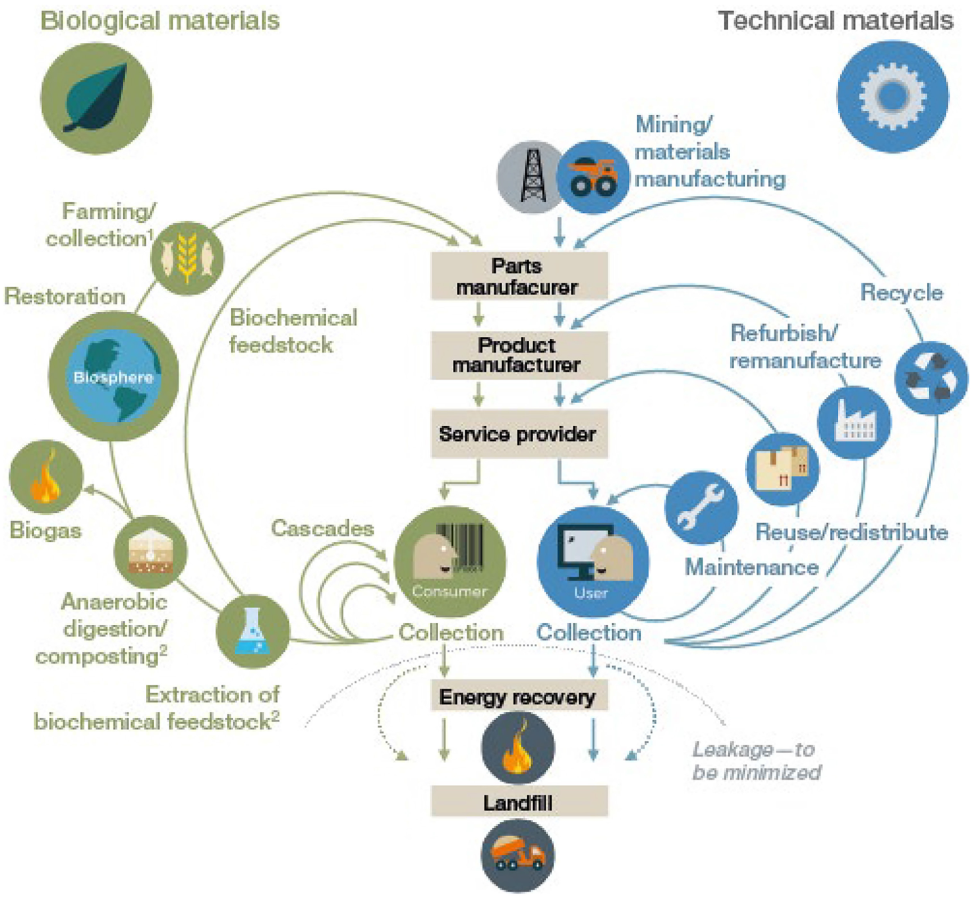
Introduction

The concept of circular economy looks beyond the current linear industrial models of “take, make, and dispose”, and instead aims to redefine products and services to design waste out, while also minimizing negative impacts of a linear economy. With scarce resources and an ever-increasing global population, the idea behind circular economy principles is to build long-term resilience, generate business and economic opportunities, and provide environmental and societal benefits.

Such an economy is based on a few simple principles, as shown in Figure 1. First, at its core, a circular economy aims to design out waste. Waste does not exist products are designed and optimized for a cycle of disassembly and reuse. These tight component and product cycles define the circular economy and set it apart from disposal and even recycling, where large amounts of embedded energy and labour are lost. Second, circularity introduces a strict differentiation between consumable and durable components of a product. Unlike today, consumables in the circular economy are largely made of biological ingredients or ‘nutrients’ that are at least non-toxic and possibly even beneficial, and can safely be returned to the biosphere, either directly or in a cascade of consecutive uses. Durables such as engines or computers, on the other hand, are made of technical nutrients unsuitable for the biosphere, such as metals and most plastics. These are designed from the start for reuse, and products subject to rapid technological advance are designed for upgrade. Third, the energy required to fuel this cycle should be renewable by nature, again to decrease resource dependence and increase systems resilience (to oil shocks, for example)[1)].

[1)] World Economic Forum. Web: http://reports.weforum.org/toward-the-circular-economy-accelerating-the-scale-up-across-global-supply-chains/from-linear-to-circular-accelerating-a-proven-concept/#view/fn-12



Key

1 Hunting and fishing

2 Can take both postharvest and postconsumer waste as an input

Figure 1 — The circular economy–an industrial system that is restorative by design

[SOURCE: Ellen MacArthur Foundation circular economy team drawing from Braungart and McDonough and Cradle to Cradle (C2C)]

The two Towards the Circular Economy reports published by the Ellen MacArthur Foundation provide ample evidence that circularity has started to make inroads into the linear economy and has moved beyond proof of concept. Several businesses are already thriving on it. Innovative products and contracts designed for the circular economy are already available in a variety of forms-from innovative designs of daily materials and products (e.g., biodegradable food packaging and easy-to-disassemble office printers) to pay-per-use contracts (for tyres for instance). Demonstrably, these examples have in common that they have focused on optimizing total systems performance rather than that of a single component.

In this context, the waste hierarchy of the Waste Framework Directive (2008/98/EC) matches with the circular design strategies set for the “Design for the Circularity” by Ellen MacArthur Foundation. The strategies are reuse, repair, remanufacture and recycling.

The European Commission adopted an ambitious Circular Economy Package, which includes measures that will help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth, and generate new jobs.

Since 1 January 2015, manufacturers must reuse 95 % of ELVs: 85 % of the materials they are made of and the remaining 10 % for energy generation (Directive 2000/53/EC). In this context, the main difficulties lie in the separation of the different components (metal, glasses, cables, etc.) that make up the parts and the removal of odours and contaminants to produce high quality granulate suitable for reuse.

Therefore, the aim of this document is to define a circular design approach with the aim of delivering long-lasting and modular products in the automotive industry that will be easy to upgrade, refurbish and reuse, to be aligned with Europe’s new regulations and to start building this mentioned transition.

1 Scope

This document tries to set design requirements that make composite products and materials in the automotive sector more easily repairable and longer lasting. Besides, it will ensure that the materials and components of a product can be more easily re-used, refurbished, and recycled, and finally, it will ensure that products are free of hazardous or problematic substances, which can hamper re-use or recycling efforts. In this sense, in this context, the most important addressed are customer perspective, health and environmental impacts and benefits and technical requirements.

2 Normative references

The following documents are referred to in the text in such a way that some or all their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15344:2007, *Plastics — Recycled Plastics — Characterisation of Polyethylene (PE) recyclates (prEN 15344 under development)*

EN 15346:2014, *Plastics — Recycled plastics — Characterization of poly (vinyl chloride) (PVC) recyclates*

EN 45553:2020, *General methods for assessment of the ability to remanufacturing energy-related products*

BS 8887-2:2009, *Design for manufacture, assembly, disassembly, and end-of-life processing — Terms and definitions*

BS 8001:2017, *Framework for implementing the principles of the circular economy in organizations — Guide*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
business model
an organization chosen system of decisions and activities that determines how it creates, delivers, and captures value over time

3.2
circular economy
a circular economy entails decoupling economic activity from the consumption of finite resource and designing waste and pollution out of the system. It aims to keep products and materials in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life

[SOURCE: Ellen Macarthur Foundation and the UKs Waste Resources Action Program]

Note 1 to entry: A circular economy should build economic and social capital and regenerate natural system. It follows the European waste hierarchy and builds upon four principles: 1. Sobriety, 2. Durability at the heart of all the products, processes, and services, 3. High value retention and high 'loopability' of materials, 4. Out designing of substances of concern and hazardous substances.

3.3
composite materials
a composite material is composed of at least two materials, which combine to give properties superior to those of the individual constituents. They typically result in lighter, stronger, more durable solutions compared to traditional materials

[SOURCE: Composites UK]

3.4
disposal
any operation which is not recovery, even where the operation has a secondary consequence, the reclamation of substances or energy

[SOURCE: EU Waste Framework Directive 2008/98/EC, article 3.19]

3.5
obsolescence
the product use cycle ends, a product becomes obsolete, when the product is no longer considered useful or significant by its users

3.6
prevention
measures taken before a substance, material or product has become waste that reduce the quantity of waste, including through the re-use of products or the extension of the life span of products; the adverse impacts of the generated waste on environment and human health; or the content of hazardous substances in materials and products

[SOURCE: EU Waste Framework Directive 2008/98/EC article 3.12]

3.7
product
product is a system made available for consumer use; it is anything that can be offered to a market to satisfy the desire or need of a customer

3.8
product integrity
term focus on the quality fundamentals with distinct rigor and discipline is necessary. The design intent and process capability must be established early in the product lifecycle. Production teams should manufacture the as designed product in a repeatable and an affordable way

3.9
product lifetime
it starts when the product is released after manufacturing and ends when the product is obsolete beyond recovery at product level

[SOURCE: den Hollander, 2017]

3.10
product use cycle
stage that starts after manufacturing or recovery and ends when the product becomes obsolete

3.11
recovery
any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function in the plant or wider economy

[SOURCE : EU Waste Framework Directive 2008/98/EC article 3.15]

3.12
recycling
any recovery operation by which waste materials are reprocessed into products, materials, or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations

[SOURCE: EU Waste Framework Directive 2008/98/EC article 3.17]

3.13
remanufacturing
industrial process which produces a product from used products or used parts where at least one important change is made to the product

[SOURCE: EN 45553:2020, 3.1.1]

3.14
repair
return a faulty or broken product, component, or material back to a usable state. A repair may use remanufactured or reconditioned parts

[SOURCE: BS 8887-2:2009 Design for manufacture, assembly, disassembly, and end-of-life processing. Terms and definitions]

3.15
reuse
any operation by which products or components that are not waste are used again for the same purpose for which they were conceived

[SOURCE: EU Waste Framework Directive 2008/98/EC article 3.13]

3.16
systems thinking
a holistic approach to understanding how different parts of a system can influence one another and the relationship of the system to the parts over time

[SOURCE: BS 8001:2017, Framework for implementing the principles of the circular economy in organizations – Guide]

3.17
waste
any substance or object which the holder discards or intends or is required to discard

[SOURCE: EU Waste Framework Directive 2008/98/EC article 3.1]

3.18
waste hierarchy
the priority order in waste prevention and management: prevention, preparing for reuse, recycling, other recovery, and disposal

[SOURCE: EU Waste Framework Directive 2008/98/EC article 4.1]

4 Design strategy framework

4.1 Design strategies

Three design approaches can be identified to reduce the input (resources) and output (waste & emission) of a system: narrowing, slowing, or closing the flow of resources through the system. Narrowing refers to using less materials, which is commonplace in product design as it results in direct cost reduction. A Lightweight design approach reduces both materials in the manufacturing stage and fuel consumption in the use phase, especially in transport applications. Slowing down the flow refers to keeping products in use for longer.

Longevity of products & components is the goal of design for product integrity, compromising three design approaches: a long product lifetime, product life extension or recovery of the product at the end of its use cycle (den Hollander, 2018). Closing resource loops is the domain of recycling, where materials are reprocessed from obsolete products into raw materials ready for a next lifecycle.

- Long lifetime is enabled by design for long use and reuse. For long use, the product life cycle is if the use cycle. Reuse aims to increase the number of use cycles within a single product lifecycle, for example by sharing.

- Extended use is enabled by actions prolonging the product life, like maintenance, repair and upgrading. Addressing these in the initial design makes the operations later in the lifecycle easier and cost effective.

- Product recovery returns obsolete products or parts thereof to working condition, returning products that risk being lost to the economy.

- Recycling recovers resources at a material level, thereby closing the loop. When the product or its components cannot be recovered anymore, recycling can return the materials to resources for new products. As all products will become obsolete one day, design for recycling is considered essential for all products.

Table 1 — Design approaches and strategies categorisation (based on den Hollander, Bakker, & Hultink, 2017)

	Circular product design			
	Design for product integrity			Design for recycling
Resources	Products and components			Materials
Approach	Long lifetime	Extended use	Product recovery	Recycling
Strategies	Long use	Maintenance & repair	Refurbishment	Composite recycling
	Reuse	Upgrading	Remanufacturing	Materials recycling

It is important to realise that these strategies do not work isolated, the system in which they are applied must be regarded as well. A design strategy will not make recovery happen. For example, refurbishment implies a long product (or component) lifetime which must be addressed; refurbishment is not interesting if the resulting product does not comply to new technical or functional demands.

Design strategies can pose multiple and sometimes conflicting demands on the product design. Therefore, it is important to consider the desired recovery process and stakeholder in the design stage, as well as developing scenarios to anticipate future changes. The measures taken to increase a product's durability or other adjustments made must be weighed against the envisioned benefits. Additional resources used in the initial production must be worth the additional lifetime, use, recovery, and recycling benefits.

Product design integrates requirements from (circular) business models and technological design aspects. The business model directs the product lifecycle; what kind of interventions will be done. When and which incentives are in place. A design strategy serves to bridge the gap to product design.

4.2 Design principles

During its lifetime, a product encounters many processes and stakeholders. In a circular economy, the number is likely to grow. It is important to gather knowledge about these processes and stakeholders and to translate these into technological aspects to include in the product design.

As specific technical aspects are product and context specific, providing universally applicable technological demands is impossible. Therefore, a list generically applicable design principles is used. Generalising these principles has the benefit of widening applicability to a large group of products and identifying similarities between technological design aspects. The design principles can be used to derive product specific design guidelines.

The set of principles proposed here builds on the circular product design framework (den Hollander, 2018). All design principles support multiple design strategies and are often interconnected.

Table 2 — Design principles

Design principle	Definition
Dis- & re-assembly	Facilitate demounting of components in a non-destructive way
Modularity	The product is subdivided in functional units which operate largely independent from each other. Use of (functional) modules within a larger frame provides benefits in all lifecycle stages (Baldwin, 1999)
Identification	"Identification utilizes engraving, labelling or marking for quick location of parts or assemblies upon which preventive or corrective maintenance may have to be performed." (Moss, 1985)

Design principle	Definition
Interchangeability	Enables easy exchange of components within an assembly. A feature that greatly benefits efficient lifetime extension and product recovery interventions
Material Selection	Selecting the material that is best suited to the design requirements of the product under consideration (den Hollander, 2017)
Surface treatment selection	A surface treatment must be selected such, that it is "best suited to the design requirements of the product under consideration"[11]
Sorting facilitation	Designing of materials taking into account the sorting stage so that the initial design does not jeopardise this process
Malfunction annunciation	Measures taken in the design to facilitate evaluation of product (structural) quality and fault isolation
Structural design	Utilizes the freedom of fibre composition and orientation within the material, having an effect on all lifecycle stages
Fastener & connection selection	Selection taking the envisioned lifetime extension and product recovery as well as material recycling processes into account
Documentation	Information about the design, materials, dimensions etc. enables multiple use cycles and proper end of life processing (recycling)
Planning	Planning is an important activity in the design of circular products. Timing, operations and incentives for future product interventions can be evaluated and anticipated for in the design
Simplify	Reducing number and complexity of the product and its parts
Adaptability	Updating allows a product to keep performing the functions it was originally designed for in a changing environment whereas upgrading enhances the functionality of a product
New business model	A business model that is better suited to operate with the product in a circular economy
Standardisation	Enforcing the commonly used paers and assemblies to generally accepted design standards of functional design attributes[2)]
EU legislation	Although this is not directly a design solution, there is a need of updating legislation across Europe (e.g., duration requirements, dismantling requirements, marking/information requirements, recycled content requirements)

5 Design methodology

Product design is an iterative process wherein different aspects of the product must be considered and reviewed. Iterations are needed because the aspects mutually influence each other.

The different activities involved in this process are the following:

[2)] Moss, M. A. (1985). *Designing for Minimal Maintenance Expense: The Practical Application Application of Reliability and Maintainability*. New York: Marcel Dekker.

- Product definition
- Explore challenges & opportunities
- Generic redesign
- Redesign: business focus
- Redesign: recovery
- Redesign: materials
- Redesign: integration
- Finalize (detailing for production)

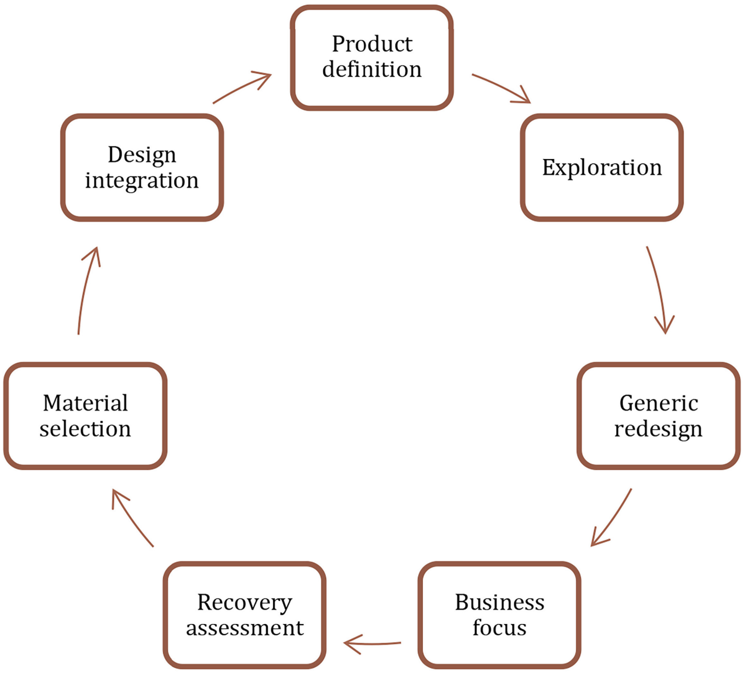


Figure 2 — Design process diagram

In order to analyse the different value chain agents' perspective and with the aim of establishing a methodology and logical process for the circular design of elements, including the recovery options, some questions should be asked in reference to several aspects:

— Material perspective:

  - What material or product is recovered here?
  - What qualities does the recovered material should have?
  - How can it be used?
  - What is needed of the material for successful (valuable) recovery?
  - Which substances does the material or product contain?

— Stakeholder perspective:

  - Which stakeholder is the material/product delivered to?

  - What requirements would he ask for?

— Business perspective:

  - What is the value proposition of this recovery?

6 Design solutions and main challenges

6.1 General

In order to identify the main design challenges and solutions (including the different approaches: product description; challenges and problems; design principles and application and effects) a workshop was held with the participation of the different stakeholders of the automotive sector. It was also considered some cases of composite products and materials in this sector. For further information, see Annex A.

6.2 Main challenges

6.2.1 Introduction

The main challenges to address in the definition and establishment of a circular design framework are:

6.2.2 Dis- & re-assembly complexity

Difficulties can arise when designing a product related to dis- & re-assembly methods: lack of space for screws, impossible to make the product modular, etc.

6.2.3 Information for self-repair by users

A catalogue of easily replaceable parts and/or elements in vehicles would be interesting to encourage repair by the users themselves, which would enhance the re-use of many parts and elements.

6.2.4 Customer design expectations

Products must be desirable for customers, which means that a product must be designed considering the opinion of the final users and paying special attention to aesthetics. In this context the difficult part is to maintain the product appealing through the time (both if the final goal is to lengthen the use or if the objective is to reuse it). To make the product timeless may be a way to get it accepted for a long time. The ability to change appearance, the exterior can be a way to give product longevity. An example is mobile phones where you can change the covers. It might be an advantage of age and wear that gives the product "patina" as extra value.

6.2.5 Mechanical requirements

When materials, the surface treatment or structural design change, it is easy that the product faces mechanical problems. Considering all mechanical and safety requirements before deciding which design solutions are going to be applied.

6.2.6 Safety requirements

Ensuring the safety of individual vehicle parts as well as the vehicle as a whole is essential for both the re-use of parts/products and the recycling of materials.

6.2.7 Modularity complexity

Difficulties can arise when designing a product to be modular: lack of space for screws, impossible to separate pieces, etc.

6.2.8 Easy replacement (assembly and disassembly)

To facilitate the re-use of parts and components, it requires not only modularity but also ease of replacement, i.e., to eliminate adhesives and glues as far as possible, and replace them with clips or press-fit elements.

6.2.9 Standardised design

In order to facilitate the replacement of vehicle parts and components, maximum standardisation in their design is recommended, not only at the level of models but also of automotive manufacturing groups (different brands).

6.2.10 Mechanical recycling challenges

The compatibility of coatings with recycling processes together with the variety in the composition of the composite materials (e.g., different polymer types, additives, fibres, coating, and fillers) can hamper the sorting of the materials and represent barriers for their proper recycling.

6.2.11 Nonexistence market

There is a lack of recycled materials in the EU market. This jeopardises the capability of doing recycled products or components. This is mainly because of the lower amount of this type of products or because it is not cost-effective either.

6.2.12 Database of recyclable materials

It is recommended that a database of recyclable materials be created to enable manufacturers to identify and introduce them into the assembly line. It will also facilitate the recovery and recycling process, encouraging the establishment of circular models.

6.2.13 Material contamination

Due to the production or the recovery processes, materials can get contaminated through many of the steps involved. Thus, assuring that recycled, reused, or remanufactured materials are free of contaminants is such a challenge.

6.2.14 Sorting challenges

Most of black plastic is coloured using carbon black pigments which do not enable the product to be sorted by the optical sorting systems being used widely in plastics recycling (NIR technology). As a result, black plastics commonly end up as residue and is disposed of in landfill or recycled into lower value materials where polymer sorting is not required.

6.2.15 Economics

Recycling will ultimately lead to resource and energy saving. Various technologies, mostly focusing on reinforcement fibres and yet to be commercialized, have been developed: mechanical recycling, solvent-based recycling, and chemical recycling. However, lack of adequate markets, high recycling cost, and lower quality of the recyclates are the major commercialization barriers. To promote composites recycling, extensive R&D efforts are still needed on development of ground-breaking better recyclable composites and much more efficient separation technologies (Yang, 2012).

6.2.16 Durability challenges

Whilst the life expectancy of products has traditionally been predicted from previous in-service experience, the use of materials in more demanding applications requires a far better understanding of the failure mechanisms that determine a component's life expectancy.

6.2.17 Regulation limitations

Products cannot be produced the way manufacturers want. They need to follow the legislation, especially the hazardous substances contents allowance, including for recycled materials for which the legislation may be more stringent than when the product was placed on the market (e.g., new bans or restrictions of substances).

6.2.18 Traceability control

Products should be identified along the whole value chain. Traceability information is important to check the origin of the products/materials, that they do not contain hazardous substances, and to know where exactly they have been along the process.

6.2.19 Adaptability issues

The key feature of a product is that it in an optimal way fulfils the customer's needs. Try to meet the customer's real needs. There are different business models that can be interesting in the case of remanufacturing. A remanufactured product can be sold to customers, but it might also be rent to him or maybe just sell the function and provide him with the necessary equipment. Products need to adapt to the customer’s requirements.

6.2.20 Collection challenges

It is not easy to collect bulky waste for the manufacturers. Once the manufacturers do not own the product anymore, it is not possible to assure entirely that they will get it back once its lifecycle has end to apply any of the recovery strategies.

6.2.21 Market of reusable ELV vehicles parts

General public attitude must change towards a more sustainable consumption habit. In this sense, it is always preferred to reuse products instead of buying new ones, and if it is essential to buy another product, check the remanufactured options (always with their quality assurance) before the totally new ones. In this context, it is considered appropriate to create a network of spaces in dealerships, garages, and repair centres where users can buy vehicle interior parts and elements that are easily replaceable and embeddable into their vehicles.

6.2.22 Environmental and health considerations for circularity

Ensuring all health and safety protocols along the entire value chain associated with circular models (direct and reverse logistics) is implicit.

6.3 Featured solutions

6.3.1 Dis- & re-assembly

Active Disassembly use design practices that incorporate smart materials and processes to enable the rapid and non-destructive disassembly of products and components. Active Disassembly address some of the barriers associated with designing for remanufacture, including cost of new design, time, labour, and quality of recovered components. Make the product easy to demount. Screws, snaps, clips are normally preferred. Welding, rivets, folding, gluing, etc. can make a joint more difficult to demount. Use the same type, and size, of joining elements (screws) to make it possible to use only one tool during demounting. Make the joining points easy to access if possible, from one side and aligned in one direction[3]. Security requirements, such as the reduced use of some materials (e.g., Velcro) must also be taken into account.

The tips for manufacturers for easy dis- & re-assembly are the following:

— Note which parts of a product may need to be disassembled at a reuse. Make these parts easy to disassemble.

— Make sure that everybody can easily access all of the items to be disassembled and that this can be done with the appropriate tool. It shall also be possible to simultaneously view the points.

— It is good if all points to be dismantled can be reached from a single direction.

— The product should have adequate fastening points so that you can manage it by a remanufacturing either on a working bench or in any equipment needed for the process.

— Sometimes it might be appropriate to leave room for new screw holes that will be needed by the remanufacturing.

— Reversible fasteners, that can be reused, is usually good.

— Show where fasteners are seated in order to facilitate the dismantling. Do not hide them. View if needed with an instruction type arrow.

— Screws are normally good for disassembly.

— Use one type and a size so that you can use one single tool.

— Make sure that you can access the screw with a tool, for example, a screwdriver. If there is a nut you must also have access to the back side.

— If possible, use screws of type Torx and Insex that does not provide the lifting forces at loss and tightening.

— Screws of type pozi-drive are also relatively good.

— Snap fasteners are good for disassembly.

— There are normal snap fasteners that are integrated into the details usually of plastics.

— There are snap fasteners that are pressed into place.

— Sometimes a Velcro can be a suitable fastener.

— Clips are good for disassembly.

— Adhesives - are generally not preferred if the product must be dismantled at a remanufacturing.

— If adhesive is to be used, the best alternatives are water-based adhesives or reversible adhesives.

3) Ellen MacArthur Foundation. Web: https://www.ellenmacarthurfoundation.org/case-studies/techniques-for-rapid-non-destructive-disassembly

— Breakpoints can be good for glued joints which must be broken.

— Rivets - are not preferred for disassembly.

— Welding - is not preferred for disassembly.

— To join parts by folding - is not preferred for disassembly.

— Staples (for staple gun) - are difficult to remove.

— Use simplified connection points.

— Prepare an assembly-disassembly manual.

6.3.2 Modularity

Enforcing "conformance of assembly configurations to dimensional standards based on modular 'building block' units of standardized size, shape, and interface locations (e.g., locations for mating attachment or mounting points and input/output line connectors), in order to simplify maintenance tasks by enabling the use of standardized assembly/disassembly procedures" (Moss, 1985). When talking about modularity, it is necessary to distinguish between the elements subject to wear and the structural elements. The former need to be changed, the latter can remain in the product.

6.3.3 Identification

Provide the product with an identification. This can be done with a tag, barcode, QR code, or even with a simple text placed on the product. Mark if possible different parts with the type of material. This will help in the traceability, making easy the recovery of products. Some examples of recycled plastics and the characteristics for their recycling are:

— Characterization of poly (vinyl chloride) (PVC) recyclates (see EN 15346:2014)

— Characterisation of Polyethylene (PE) recyclates (see EN 15344:2014)

6.3.4 Interchangeability

"Controlling dimensional and functional tolerances of manufactured parts and assemblies to assure that [a part that is expected to fail or has failed] soon can be replaced in the field with no physical rework required for achieving a physical fit, and with a minimum of adjustments needed for achieving proper functioning" (Moss, 1985).

6.3.5 Material Selection

Use materials, parts and components that will be available in the future. Keep in mind the second use of a remanufactured product. Use materials that do not degenerate during the multiple use faces. Pay attention to chemicals and additives that can be present in materials. Avoid those that now or later are harmful and might be banned. Avoid those that can cause problems during the remanufacturing process. REACH is a regulation with a list of banned materials and a list of materials to be banned. Consider multiple lifecycles. Use materials which are strong enough. Avoid materials that might lose strength, become brittle or get discoloured. Do not incorporate any chemicals that might be banned later. Avoid the use of toxic compounds such as hexavalent chromium coatings and substitute by other plating or plating processes. Replace the chrome finish with painted.

6.3.6 Surface treatment selection

Selecting the type of surface treatment (for example anodizing, painting, plating, or coating (Bijen, 2003) best suited to the design requirements of the product under consideration.

The surface of a product is the visible part, hence, if it is damaged the customer will think of changing the product for a new one. Coatings which help to avoid scratching will improve the appearance of a product, making its life longer. Select the surface treatment that is resistant to the desired number of lifecycles. Select surface treatment which can be removed if it must be renewed. No toxins should be present. Make sure that in case of being recycled this coating will not negatively affect the recycling process. Whenever possible, functionalise the surface without adding any material on top of it. For example, surface texturing could be used to provide specific surface properties in a mono material approach.

6.3.7 Sorting

Each product needs to be sorted. This could happen by density, with a magnetic or electric field, or by using other physical or mechanical characteristics of the material we want to separate. The chosen mechanism depends on the material mix. Ferrous materials are easy to separate from aluminium by using a magnetic field. Moreover, more and more parts under the bonnet are made of PA (polyamide) as substitution of metallic parts. The efficient recycling of polyamides requires to be able to sort different forms of PA, e.g., PA6, PA6-6, PA11, PA12, which is nowadays not possible using existing industrial means.

Another challenge of sorting for plastics is the PP (polypropylene) owns the highest share of plastic materials in cars, and by way of consequences is also the most valued plastic in the recycling of ELVs. However, PP is basically used in two different forms in cars: non filled PP and talc-filled PP. Because of its higher density, talc-filled PP is not properly recovered after sink float separation and is mixed with other plastics in a difficult-to-recycle blend. This significantly decreases the economic balance of plastic recycling from ELVs. More homogeneity in the use of PP materials in cars should be proposed to enable full recovery of PP.

Be aware of how the sorting process of the product works to make a good selection of materials and shapes so that it can be sorted efficiently.

6.3.8 Malfunction annunciation

Add a structural way to obtain a diagnostic of the old, worn out product. This assists you to clarify what must be done to the product to give it a second life.

6.3.9 Structural design

Try to gather all parts that need to be updated in one subassembly. Avoid cross-dependencies that makes it necessary to update one module because of updating in another one. Make a "kit" with all the elements required for an update.

6.3.10 Fastener and connection selection

The product should have adequate fastening points so that you can manage it by a remanufacturing either on a working bench or in any equipment needed for the process. Sometimes it might be appropriate to leave room for new screw holes that will be needed by the remanufacturing. See point “Tips for manufacturers for easy dis- & re-assembly”.

6.3.11 Documentation

Save data about the product on the web or in any other suitable way. Appropriate data can be content of materials and procedure for the remanufacturing, but it can also be any other data regarding the product. There must be product information, also a link where the data about the product could be found. Give information about how to make the product last longer and how to dispose it to give a second life to the product.

6.3.12 Planning

Start the designing phase by thinking in all stages of the products life and all lifecycles available. Consider all possible design solutions during the design process. An initial LCA can give very useful information for decision-makers to decide which of the alternatives can be more appropriate to close the loop of the product.

6.3.13 Simplify

Try to reduce to the minimum the number of pieces and parts of each product.

6.3.14 Adaptability

Allowing a product to be continually updated (Keoleian, 1993) or to “perform several different functions” (Keoleian, 1993).

Updating allows a product to keep performing the functions it was originally designed for in a changing environment whereas upgrading enhances the functionality of a product.

6.3.15 New business models

Although this is not directly a design solution, there is a need to stablish a solid market around circular economy. Products should be part of an integrated business model focusing on the delivery of a performance or functional service. Competition should be mainly based on the creation of added service value of a product, not solely on its sales value. Social/business model innovation allows the creation of extra value by applying technological innovation to solving societal needs. As products are part of a company's assets, cost minimisation drives product longevity, reuse, reparability, and remanufacturing.

6.3.16 Standardization

Enforcing “the conformance of commonly used parts and assemblies … to generally accepted design standards for configuration, dimensional tolerances, performance ratings and other functional design attributes” (Moss, 1985).

6.3.17 EU legislation

Although this is not directly a design solution, there is a need of updating legislation across Europe (including health, safety, and environmental issues). This can be introduced through new resource efficiency and material requirements (e.g., on duration, dismantling, marking/information, recycled content) in product legislation.

6.4 Challenges and solutions for composite recovery in the automotive industry

6.4.1 General

Nowadays, the design of the vehicles does not help plastic parts recovery at all. This is because the vehicles arrive in very bad conditions or compressed to recycling and recovery process. Moreover, they are mechanically crushed to make the separation of the components easier. If a priori separation of the fragmentation process is to be proposed, the market value of recovered material should be higher than the cost of its extraction.

The main points to separate a part are the following: easy identification, size and profitability of the operation, which combines ease of extraction, and high possibility of reusing for the same purpose or another of enough economic value. Legislation also boosts these actions, as it is the case of fuels, oils, and lead batteries, which are compulsorily extracted.

In scrapping it should be possible to locate and separate the most important parts to recover, before or after the first pressing. This should be easy should in terms of material, size or colour and low manpower.

6.4.2 Main challenges

The main challenges which the automotive sector may face when designing for a circular economy are related with the customers’ perspective about a remanufactured or reused product. In this sense, some of them are:

- Product appearance: It is extremely important, hence is a matter of change people’s mindset to make them understand that a reused or remanufactured product is not worse than a new one.

- Mechanical properties: This points out if a reused or remanufactured product will have exactly the same mechanical requirements as a new one.

Moreover, considering the manufacturers’ and Authorised Treatment agents’ perspective, the main challenges facing the recovery are

- Disassembling process: The ease of identification, disassembly and separation activities (including the substitution and phase out of substances of concern and materials or components which do not fit into a circular model because they hamper circularity objectives) and their costs (complexity and resources) are critical to ensure the profitability of a circular model (e. g. by unifying the plastics and composites or developing more effective methods of classification and recovery of these for re-entry into the industrial cycle again).

- Economical and technical viability of processes: Feasibility of applying physical-mechanical and chemical techniques to recycled elements for their reintroduction into the production chain.

Table 3 — Summary of the most important challenges of the automotive sector

Main Challenges Automotive	Materials	Products			
	Recycling	Remanufacturing	Refurbishing	Re-use	Longuse
Dis- & re-assembly complexity	X	X			
Information for self-repair by users				X	
Customer design expectations		X	X	X	X
Mechanical requirements	X	X	X		X
Safety requirements	X	X	X	X	X
Modularity complexity			X		
Easy replacement (assembly and disassembly)			X	X	
Standardised design				X	
Mechanical recycling challenges	X				
Non existing market					
Database of recyclable materials	X				
Material contamination	X				
Sorting challenges	X				
Economics	X			X	
Durability challenges			X		X
Regulation limitations					
Traceability control					
Adaptability issues					
Collection challenges					
Market of reusable ELV vehicles parts	X			X	
Environmental and health considerations for circularity	X				

6.4.3 Design solutions

When designing a product, several aspects must be taken into account. Specifically, the right material should be sought in order to fulfil the product requirements in the short, but also in the long term. Besides, with the objective to reuse it afterwards, as simplicity as possible is needed in its design. The simpler the product, the more reusability. Related to that, the most suitable design solutions in the automotive sector are shown in Table 4.

Table 4 — Summary of most suitable design solutions for the Automotive sector

Main Challenges Automotive	Materials	Products			
	Recycling	Remanufacturing	Refurbishing	Re-use	Longuse
Dis- & re-assembly complexity				X	X
Modularity	X			X	
Identification					X
Interchangeability					
Material selection	X	X	X	X	
Surface treatment selection			X	X	
Sorting	X				
Malfunction annunciation					
Structural design	X	X		X	
Fastener & connection selection			X		
Documentation					
Planning				X	
Simplify	X	X		X	
Adaptability				X	
New business model				X	
Standardisation	X			X	
EU legislation	X			X	

Specifically, the following criteria and initiatives should be sought:

- High modularity in the design and manufacture of the different elements.
- Simplicity and lightness of elements, without compromising their structural and functional characteristics.
- Automation of the processes of identification, dismantling and separation of the elements at the end of their useful life.
- Building incentives (perhaps economical) for institutions/companies and/or end-users to disassemble components at the end-of life of cars.

Finally, in order to develop and validate the proposed methodology, it has been decided to work on the concepts described in the following products, corresponding to the light fraction of the vehicle:

Table 5 — Baseline products and selection criteria

Sector	Application	Material(s)	Reference Product(s)	Selection Criteria			
				Currently difficult to be Recovered Recycled	Currently difficult to be Recycled Reused materials	Critical application	Circular economy potential application
Automotive	Car interior	PC+ABS	Fascia Central Console	Y	Y	N	Y
		Metal	Safety belt brackets	Y	Y	Y	N
		ABS	Trim for central panel	Y	Y	N	N
		ABS	Centre Console Cowlings	Y	N	N	Y

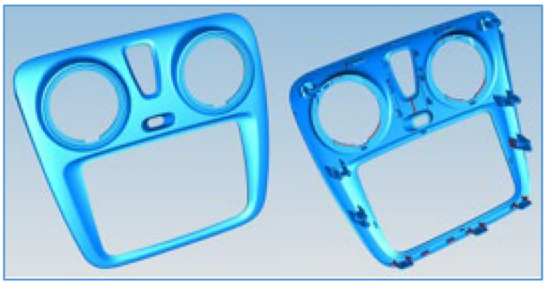


Figure 3 — Prototypes Design

Annex A
(informative)

Workshop with automotive sector stakeholders

A.1 General

A workshop held with different stakeholders of the automotive sector delivered valuable insights in the challenges and opportunities for circular redesign of the reference products. These observations were used to compose individual redesign assignments for the manufacturing partners. The redesign approach has four sections:

— Product description: detailing the reference product and design requirements.

— Challenges & problems: establishing two major concerns found in the workshops.

— Design principles: Proposing design principles that can help solve the problems.

— Application & effects: redesign of reference product & evaluation of result.

A.2 Challenges & problems

For each reference products, two major concerns were identified from the workshop and questionnaire. In total, four main challenges were found:

Table A.1 — Main challenges

Dis- & re-assembly	Removing the components from the product assembly and mounting them in a new product.
Physical durability	Withstanding degradation and ageing effects over the product's service life.
Emotional durability	Keeping the product desirable for the consumers, i.e., resisting changes in fashion and design appearance.
Repair of material	Keeping the product functional requires maintenance or repairs, which can be enabled through careful design and material selection.

A.3 Design principles

The workshop & questionnaire also asked participants for design suggestions to address these challenges. The suggestions were categorised using the design strategy framework, and a shortlist of most design principles deemed most relevant was made, definitions of the listed principles can be found in Clause 4.2:

— Adaptability

— Interchangeability

— Modularisation

— Standardisation

— Surface treatment

A.4 Application

A.4.1 General

The manufacturers were asked to apply these design principles in their redesign and evaluate the results, reflecting on the initial challenges. The following subclauses provide a summary of the redesign progress.

A.4.2 Stakeholder 1

The fascia is a component of the central console. It is made of several parts (frame, fascia, and fasteners) assembled to the vehicle by snap-fits and screws. Although it is designed as a structural support (electronic system, aerators, screens) the aesthetic finish is the main functionality. All the parts of the component are made of thermoplastic materials by injection moulding. Due to different aesthetic and technical requirements, most of the finishing surfaces are made by coating, painting, or plating processes before the assembly operations.

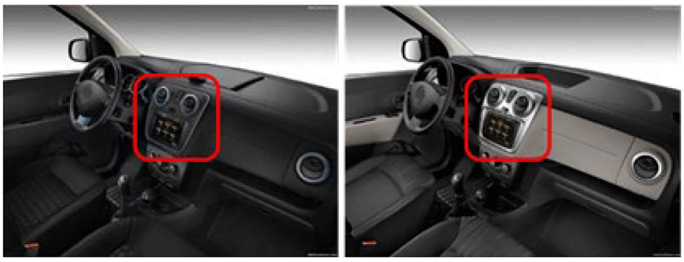


Figure A.1 — Stakeholder 1 reference product

Table A.2 — Main challenges identified (Stakeholder 1)

Challenges & problems	For your product, the two main challenges identified during the workshop were:
Dis- & re-assembly	Regulations dictate the component must be designed to allow the easy Dis+Re-Assembly operations for the maintenance operations and at the End of Life of the vehicle.
Physical durability	Withstanding degradation and ageing effects over the product's service lifes. The durability of the component depends mainly on the resistance (light, chemical, abrasion) of the aesthetic surface finishes. Reinforced and/or Recycled thermoplastic materials negatively affect the aesthetic finish of the painted parts with lack of adhesion, heterogeneity and reproducibility of colour and gloss.

Proposal of redesign of the component: integration of functions in a single part injected in two materials. Top side made of conventional thermoplastic compatible with coating/paint processes for the aesthetic finishes; Back side made of reinforced/recycled thermoplastic; fixations (snap-fits, clips) on back side get from the injection step.

Figure A.2 — Stakeholder 1 product redesign

Table A.3 — Effects (Stakeholder 1)

Effects	Evaluation of redesign
Dis- & re-assembly	Easier Assembly/Disassembly operations due to the reduction of parts for a multi-functional component. Easier recycling operations due 2K parts made of fully compatible materials.
Physical durability	Possibility of aesthetic finishes based on natural, reinforced and/or recycled materials (Composite Aesthetics). Possibility of improving the use of recycled materials (on back side of the component).
Remaining hurdles	The performance of (recycled) materials: Processability (injection moulding), actual performance (mechanical, thermal, chemical), light stabilization and thermal aging, compatibility with finishing processes according to aesthetic specifications for automotive interior applications.

A.4.3 Stakeholder 2

Two car interior components are considered for redesign: dashboard cowlings and switch pack housing. The dashboard cowlings house the display and consists of multiple parts. The front surround of the main display is now clipped onto the aluminium support frame which holds the display. The rear portion of the cowling is them bolted through the back into the frame. This system is good for quick disassembly.

The switch pack cowling is similarly slipped over the switch bracket and screwed in place with self-tapping screws from behind. As this part is continually touched by the driver whilst operating the switches it is subject to the most wear and tear, so will need to be refurbished more often than other parts.

Figure A.3 — Stakeholder 2 product prototypes

Table A.4 — Main challenges identified (Stakeholder 2)

Challenges & problems	For your product, the two main challenges identified during the workshop are:
Dis- & re-assembly	There may be an issue with bolts that could be removed by the user in the 2 cases mentioned here. These may have to be covered with caps to prevent unwanted access by users or non-service personnel. We will have to look at time taken to build up these parts and systems as long build time will tend to raise costs of product.
Emotional durability	In terms of emotional durability, 'design for circularity' needs to develop its own language so that users become familiar with why things are styled in certain ways to allow for remanufacture.

The main thrust of the design process has been towards modularization of parts to allow replacement of small parts as and when necessary without having to 'scrap' large elements. The second most important consideration is that of surface treatment of the parts. Some of the materials which are coming through new circular models have quite interesting aesthetic qualities which may be suitable in the wider context of our vehicle interior designs. An attempt shall be made to use the materials as they are (natural) without having to treat them superficially (e.g., with paint). In this way, a positive statement is made about the choice of materials and no attempt is made to disguise them and make them look like something else.

Table A.5 — Effects (Stakeholder 2)

Effects	Evaluation of redesign
Dis- & re-assembly	An improvement on the previous design which was very difficult to disassemble and required a lot of preparation and surface treatment.
Emotional durability	This has to be tested with a user group, but the design team and other colleagues are pleased with the direction the design is taking.
Remaining hurdles	To identify recycled materials for use & to examine the cost of the build process in detail.

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