SALIENT

Safer, Lighter, Circular, Smarter

Ecodesign guide for the automotive industry

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1. EXECUTIVE SUMMARY

This ecodesign guide, developed under the framework of the EU-funded SALIENT project, aims to provide an overview of the role of ecodesign principles within the circular economy model applied to the automotive industry. From the introduction of this concept, as a breaking point with the traditional design methodology, to becoming an essential part of product conception, the rapid evolution of ecodesign practices stands symbolically for the relevance and impact of integrating environmental and sustainability criteria into product development of automotive products, parts and design today and in the near future.

Understanding the methodology behind ecodesign practices is essential to grasp the effect of its applications on the final product designs. In this document, the whole ecodesign process is presented and explored, including the analysis of the most relevant environmental design methodologies, their evaluation criteria and the final integration of these environmental parameters together with the technical requirements.

As a final chapter, the application of this methodology in a real automotive study case, as part of the SALIENT project, is presented. The aim is to provide the global overview of the ecodesign: from the definition of the concept to its actual application procedure.

2. WHAT IS ECODESIGN?

Ecodesign has become an essential part of any new product development. Its implementation in the early design stages sets the framework not only for the design development itself, but also for the later stages of the product life cycle.

It may seem an obvious question, but the actual definition of **ecodesign** is not always clear. Commonly defined as the cornerstone of the circular economy, it is essential to first understand the importance of the **circular economy** model, the framework that led to the emergence and development of this design methodology.

Figure 1: Tyre disposal.

In 1987, the economic, political and social context led to the publication of a report by the World Commission on Environment and Development (WCED) titled "*Our Common Future*" [1]. This document, known also as the "*Brundtland Report"* after Gro Harlem Brundtland, the World Commission's Chairwoman, established the urgency of the transformation of the economic model, due to the scarcity of natural resources, towards a development model which would not compromise the needs of future generations. It was the introduction of the now common term **sustainable development** [2]. The subsequent introduction of the term **ecological design** in the late 1990s and the following evolution of this concept are merely a consequence of this change in society's mentality.

The circular economy brought about a paradigm shift in existing production models, establishing a new model in which the use of resources is optimised, the product life is extended, and waste is revalued. This model is based on three well-known principles: **reduce**, **reuse** and **recycle**.

Furthermore, the circular economy is based on the concept of **life cycle thinking**, according to which the life cycle of any product is divided into three main phases: **manufacturing**, **use** and **End-of-Life (EoL)**. Typically, manufacturing comprises the design, production and distribution stages, but it is also a common practice to separate the extraction of raw materials as a phase in its own right. It is important to understand that this life cycle analysis depends on the specific study case and that the actual level of **complexity** of such an analysis goes beyond the main phases presented here as an overview of the life cycle thinking. For example, as depicted below, the fuel cycle is generally considered as an additional phase of a vehicle life cycle.

Any design decision must be made based on measurable data, given the impact it can have on the product. Regarding the application of environment-related decisions, **Life Cycle Assessment (LCA)** is the tool employed for measuring the environmental impact of a given product throughout its entire life cycle. These data are the result of a **detailed evaluation of all the inputs and outputs** involved in the different phases of the life cycle: **extraction of raw materials, manufacturing processes, distribution or waste management**, among others. The LCA provides numerical data on a product's emissions, resource consumption, waste generation or material and energy requirements.

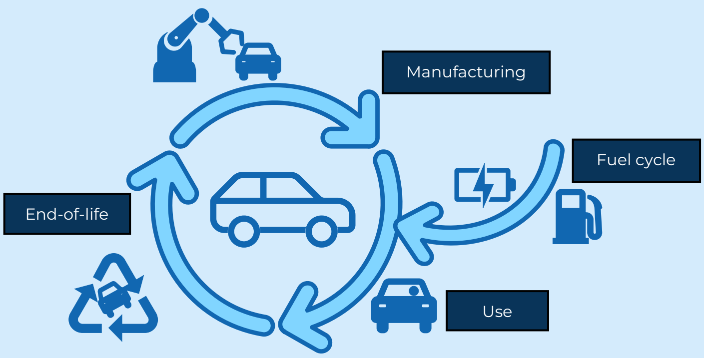

Figure 2: Life cycle stages of a vehicle.

Ecodesign aims to minimise the environmental impact of a product by **integrating environmental considerations in the early stages of its development**, where up to **80% of the product's environmental impacts** are determined [3]. The effect of these considerations not only impacts the design stage itself, but also the entire manufacturing, use and the End-of-Life phases of the life cycle of the product. These environmental considerations, which will be explained in detail in this report, relate to **energy consumption, the use of raw and recycled materials, as well as recycling and design modularity**, among other things.

The implementation of environmental considerations beginning at the conceptualisation of a new product means that environmental improvements can be achieved at low cost [4], since the reduction of this impact **no longer involves an additional stage of the design**. Furthermore, given the development and evolution of the legal frameworks within the European Union concerning all life-cycle stages of automotive products, ecodesign allows to **tackle sustainability targets in a preventive way**, ahead of the development of future environmental legislation.

The importance of ecodesign is of **high relevance for the automotive industry**. From an initial development focused on the reduction of greenhouse gas emissions related to the use phase of the vehicle, the emergence of **electric vehicles (EVs)** raised new environmental challenges and questions. The need for an **energy transition** of energy systems towards renewable sources, the attention to the **manufacturing-associated greenhouse gas emissions** or the optimisation of energy usage during the use phase have become matters of significant relevance nowadays. Given the additional complexity that these issues bring to the requirements for new vehicle designs and performance expectations, the availability of **environmental impact assessment methods** for the conception of a product has become a critical factor.

As an overview of the **current legal framework**, the **2009 UE *"Ecodesign Directive"*** established a framework for **performance criteria** to be met by manufacturers of energy-using products [5], [6]. As for the implementation of the circular design measures for all products in the EU, they were announced for the first time in 2019 as part of the ***"Green Deal"*, aiming for net zero emissions economy by 2050**, and adopted in the "*New Circular Economy Action Plan*" (CEAP) in 2020 [3]. Concerning the automotive industry, the **2000 *"Directive on End-of-Life vehicles"*** (ELV Directive) (reviewed in 2021, resulting in a proposal for new regulation in 2023), aims to **prevent and limit waste from End-of-Life vehicles and their components**, as well as to improve the environmental performance of all economic operators involved [7].

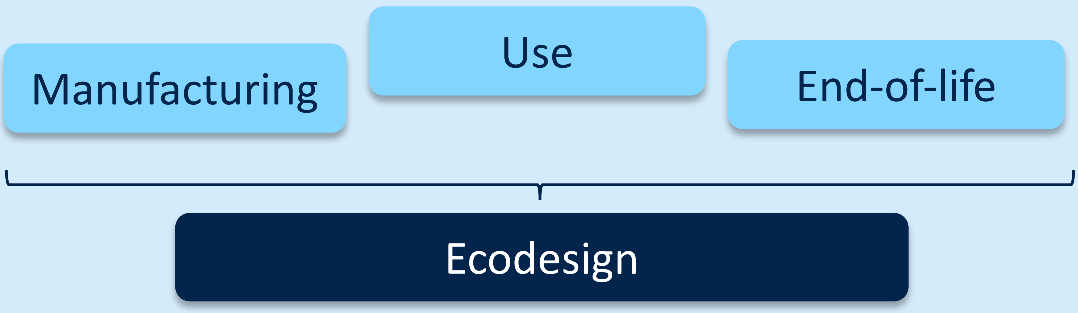

Figure 3: Life cycle stages influenced by ecodesign.

3. METHODOLOGY

The goal of ecodesign practices is to **minimise the environmental impact** of the product. To achieve this, some common guidelines are usually applied, but the selected criteria depend on the study case.

The introduction of ecodesign meant an evolution of the traditional design methodology and the so-called ***"end-of-pipe"* solutions**. This term is often employed in water or gas decontamination processes, where **action is taken in the stage prior** to the release of the contaminated flow into the environment.

This can be extrapolated to design methodologies in which the **environmental impact of a product or system is reduced by acting on the full design**, trying to minimise the impact of these measurements on the technical performance of the same, once the design is already complete. Alternatively, for new products, ecodesign entails the integration of these criteria from the conception of the design, thus leading to more efficient and less resource-consuming products.

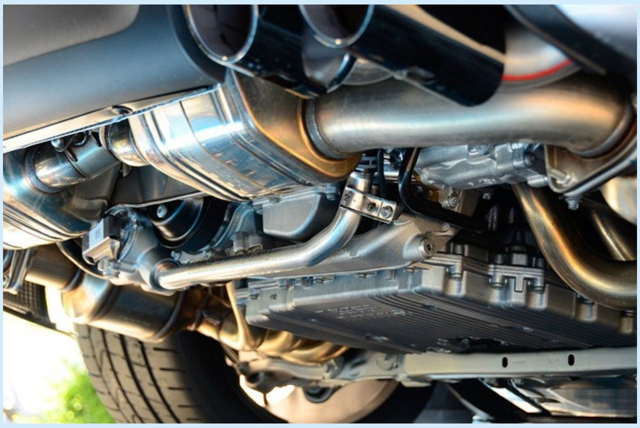

Figure 4: Exhaust system of a vehicle.

Ecodesign is sometimes referred to as **Design for Environment (DfE)**, making reference to the **Design for Excellence (DfX)** paradigm. This paradigm represents the design methodology based on a certain **external** "X" **requirement**.

These requirements can be any **aspect**, life cycle **phase** or **stakeholder** that is considered relevant to the product conception, such as manufacturing, supply chain or reliability. Fields such as electronics, construction [8] and street lighting infrastructures [9] apply this design methodology, resulting in an **extensive** list of possible requirements like usage, supply chain, maintenance or logistics.

Design for Excellence was not initially approached from an **environmental** point of view. At first, the focus was on the **efficiency** aspect of the design: how to maximise the product capabilities while optimising the **cost** and the use of **resources** throughout the whole life cycle. However, the development of **ecodesign** methodologies gave rise to a new paradigm within Design for Excellence (DfX) itself [10], [11].

Figure 5: Design for Excellence structure.

Some of the most representative DfX **principles** [12] and some guidelines related to Design for Environment are presented in the following table:

Table 1: Design for Environment principles.

Principle	Definition
Recyclability	The **use of recycled materials** reduces the raw-material and energy consumption linked to their production: • **Maximising** the use of **recycled** materials as inputs for the new product. • Selecting **recyclable** materials to allow their re-entrance in the life cycle of the product.
Minimise material usage	**Optimisation of the geometrical design,** reducing the extraction and processing of raw materials required: • **Component integration** under a single geometry. • **Weight saving** by reducing the size and using tailored materials for the desired functionality.
Durability	**Increase of the lifespan,** leading to a decrease of the resource consumption and waste generation: • Enhancing **repairability** by developing modular designs. • Defining **joining** techniques that maximise the strength and the stability of the product.
Disassembly	Simplification of the recycling process, meaning a **decrease of the cost and effort** of the material **separation** and enhanced component **recovery** at the End-of-Life: • **Simplification** of the structure of the product. • Definition of **detachable** joints
Energy Efficiency	**Minimisation of energy consumption** during the use phase of the product: • **Weight saving** of energy-using products by assessing the **material definition**.
End-of-Life	**Reduction of waste generation** at this phase: • **Elimination** of any **harmful** substances of materials that could affect this stage. • Allowing **material separation** for efficient **recycling** processes. • Development of **reusable components** after the use phase of the product.

The selection and implementation of these principles **is not limited to a single approach**, but meeting all requirements is also often not feasible, as these criteria may conflict at some point. An example from the SALIENT project illustrates such a conflict: composite materials generally add complexity to the recycling process since their mechanical properties degrade significantly and due to the difficulty of their component separation. However, during the use phase of the product, they often represent a notable advantage due to their low density combined with a high mechanical performance. Therefore, the environmental requirements need to be prioritised and achieving **the best possible balance between them is key for the design stage**.

The wide range of environmental and technical factors that can influence product design can give rise to **a number of "X" methodologies** that may be confusing when faced with a new product design. Nevertheless, when analysing the main methodologies, as presented in this document, some **common factors** can be extracted:

- **Recyclability:** the use of recycled material should be maximised, as well as the efficiency of their own recycling at the End-of-Life of the product. Here, the availability of **energy-efficient processes with low degradation of properties** is essential to allow for an enhanced material circularity.

- **Material savings:** deeply related to the reduction of raw-material extraction, an optimised use of the materials is a common concern of designers. **Optimisation of mechanical properties** in composite and multi-material solutions and the own optimisation of the **geometric design** of the product can lead to significant material savings.

- **Modularity:** this factor is particularly linked to the design aspect of the product. The possibility to assemble and disassemble leads to an **increased lifespan due to an increased repairability**. In addition, material separation and recycling at the End-of-Life handling become notably more efficient.

The detailed analysis of each particular product may lead to **different priorities depending on its function, environment or technical requirements**, but these three parameters are generally essential at the conception of a new design.

When it comes to the evaluation of the environmental criteria for a new product design, the optimal solution is a decision **based on a full LCA analysis**, where the effect of any decision can be assessed through a numerical estimation of its environmental impact. This impact is assessed in different **impact categories**, as presented in the so-called **Life Cycle Impact Assessment (LCIA):** climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related), respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use and resource depletion [13]. Depending on the assessed study case, the most relevant impact categories are identified. For an automotive study case, for instance, the **climate change potential**, **human toxicity**, **ecotoxicity** and **resource use** would be especially relevant.

Unfortunately, the development of a full LCA is sometimes excessively time-consuming to provide a real-time assessment at the design conception stage. Consequently, alternative methods are necessary to address decision-making as a complement to the LCA or to provide some impact estimation of a proposed design. In this document, a **matrix assessment** will be explained in detail, as part of the ecodesign application in the SALIENT project.

Finally, one **overarching, critical requirement** must be considered and evaluated for any design solution. Regardless of performance and potential impact, its **cost structure must be assessed**. There is no ecodesign without an economic aspect [14].

4. RELATIONSHIP BETWEEN WEIGHT AND ECODESIGN

Lightweight designs and materials of high importance to the automotive industry. Despite generally being considered a purely technical factor, **weight saving** is strongly related to environmental design.

Materials research is constantly searching for new materials with extraordinary properties: **conductivity, chemical, mechanical and many more**. **Composite materials** opened the door to the tailoring of the material: providing a material specifically designed for a certain application, in order to achieve the best possible technical performance. At the same time, the *"old guard"* materials such as **steel or aluminium** have not stood still either: constant research has led to **new alloys** with improved chemical, mechanical and manufacturing properties. Industry is constantly evolving towards the perfect material for every application.

Weight saving is a major concern of industry, especially when it comes to the automotive and aerospace industries. The reason is simple: any **object with energy consumption related to its use phase will increase its energy efficiency as its mass gets decreased**. In the case of automotive industry, it is currently in the midst of a **transformation from thermal engines to new propulsion systems**, mainly electric vehicles (EVs) on the current market. EVs are significantly heavier than the traditional thermal vehicles, with a notable percentage of this weight located on their batteries. As a consequence, energy efficiency is critical to achieve a double objective: on the one hand, to **increase the driving range of the vehicle**; on the other hand, to reduce weight to **improve road safety**.

Lightweighting might seem like a simple process, mainly related to materials: changing the structure of a car by using a lower density material would directly decrease the weight by a great percentage. Unfortunately, it usually is quite more complex than a simple change of materials. In addition to the weight savings the implementation of these materials may entail, **lightweighting is also related to the geometric design** aspect: the optimisation of a given geometry to decrease the material use, even without requiring the change of the manufacturing material, or creating new designs that integrate several parts into a new single component are aspects of great importance for this technique.

Taking a look back at the DfX methodologies described as part of the ecodesign in the *Methodology* section, the link between the lightweighting and two of the aforementioned methodologies stand out:

- **Design to Minimise Material Usage**: optimisation of the design in terms of material and geometry leads to a **reduction in both the raw material resources** required, and the **waste generated** at the End-of-Life.

- **Design for Energy Efficiency**: this is directly related to the main objective of lightweighting itself, as lighter designs will imply a **decrease in the energy consumption** during the use phase. This applies to both the thermal and electric vehicles.

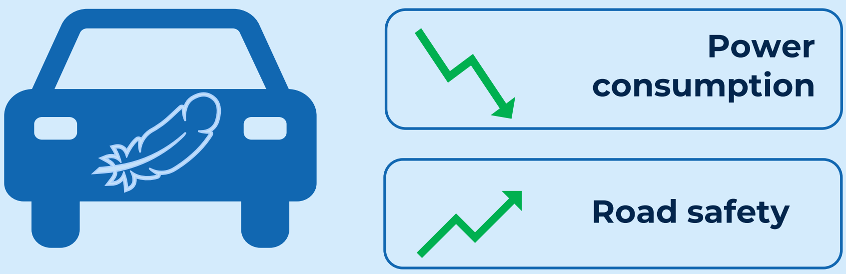

Figure 6: Impact of ecodesign on the use phase.

5. SALIENT: ECODESIGN APPLICATION IN AN AUTOMOTIVE STUDY CASE

As part of the SALIENT project, the **Front-End Structure (FES)** of a vehicle has been redesigned following the ecodesign principles presented in this guide: from the definition of requirements to the design development.

Firstly, the **Front-End Structure (FES)** of a vehicle is the subsystem consisting of the following components, as depicted:

1. **Bumper beam**: horizontal beam that connects both sides of the FES and acts as the first layer during crash.

2. **Pedestrian protection beam**: in this case, this lower horizontal beam is intended to protect pedestrians, preventing them from getting under the vehicle that during a crash.

3. **Crash boxes**: deformable components located on both sides of the bumper beam and the pedestrian protection beam. Their function is to absorb most of the energy in low-speed crashes, preventing damage to the rest of the structure, thus reducing repair costs.

4. **Vertical supports**: vertical members on both sides of the FES. They are the interface between the subassembly formed by both beams and crash boxes and the rest of the body-in-white of the vehicle.

5. **Upper and lower crossmembers**: horizontal components connecting both ends of the vertical supports.

As part of the SALIENT project, some additional components were added to the scope:

6. **Struts**: longitudinal rails located behind the upper crash boxes. They absorb most of the impact energy in high-speed collisions.

7. **3rd load lines**: longitudinal components located behind the lower crash boxes. They supplement the energy absorption of the struts.

This structure is critical in terms of safety due to its role during frontal crash scenarios as it will **define the load transmission and the related energy absorption**. Therefore, any redesign affecting these components must be evaluated in terms of the effect it may have on crashworthiness.

The redesign of the Front-End Structure in SALIENT involved the following objectives:

- **Improved crashworthiness performance** in frontal crash scenarios, with crash angles from 0° to 30°.

- A **42,7 % weight reduction** from the initial reference model available on the market.

- **Modularity**: the whole system should be replaceable for EoL or repair treatments after impact.

- The cost of the FES should be reduced by **3–4 €/kg** of material.

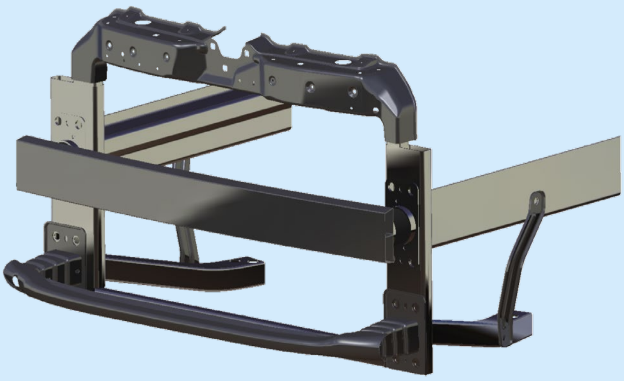

Figure 7: Front-End Structure developed in SALIENT.

The first step of a redesign is to define all of the technical requirements of the product. **Ecodesign must always meet the technical requirements the product must fulfil**, as these have priority for the usability of the project. A clear example of this would be not meeting the required safety levels: regardless of the environmental impact of the new design, it would not add value, as the product would become non-performant.

Once all the technical requirements have been clearly defined, the **analysis of the priority DfX methodologies** for the development of the product allows establishing the most important factors to be considered. The main priority methodologies for SALIENT are:

- **Design for Recyclability**: material selection must be defined aiming for maximum the recycling efficiency at End-of-Life.

- **Design for Assembly/Disassembly**: FES must be easily disassembled from the rest of the body-in-white of the vehicle. This feature is intended to improve the repairability of the system and the related repair costs, thus extending the lifespan.

- **Design for Minimal Material Usage**: as presented in the section 4: *Relationship between weight and ecodesign*, the optimisation of the material use would positively affect the energy consumption of the vehicle during its life phase.

This leads to the definition of the **specific assessment factors**, resulting from the integration of environmental methodologies and technical requirements. For the present study case, they would be:

- Recyclability
- Weight saving potential
- Assembly/Disassembly
- Component integration
- Assembly line compatibility

These factors are **evaluated for each component and for all possible materials**, giving them a **value from 1 to 3**, wherein 3 is the best solution. In addition, as not all of the factors have the same impact on the result, they are **weighted according to their relevance**. As an example, any significant incompatibility with the existing assembly line machinery and procedures could imply an economic cost and an increased resource consumption.

Table 2: Material Matrix Assessment

	Weight saving potential				Recyclability				Factor n	
Component	Material 1	Mat. 2	Mat. 3	Mat. 4	Mat. 1	Mat. 2	Mat. 3	Mat. 4	Mat. 1	Mat. n
Part 1										
Part 2										
Part n										

This evaluation method is defined as **Material Matrix Assessment**. It provides a numerical end result to evaluate the material selection and defines in quantitative terms the **material which would be the most suitable for a given component**, concerning the stated technical and environmental requirements. Depending on the specific study case, instead of evaluating each part, a complete design or more specific features (i.e. fibre options for a composite material), could be evaluated.

The output from this evaluation is the **conceptual design**: a first approach of the material definition of the different components involving the scope of the new design. A first **evaluation of the joining between components** is performed in order to assess the assembly/disassembly potential of each component and an initial analysis of the manufacturing processes required is carried out as part of the assembly line compatibility evaluation.

The first geometric redesign of the product aims for a **manufacturable geometry** and leads to what is defined as **baseline design**.

As a final step of the redesign stage, the design optimisation will evolve **based on the results provided by simulations**. At this point, it should be checked whether the proposed new design, while complying with the environmental requirements, would **meet the technical objectives** set for the project. The validation of the design would bring the ecodesign process to an end.

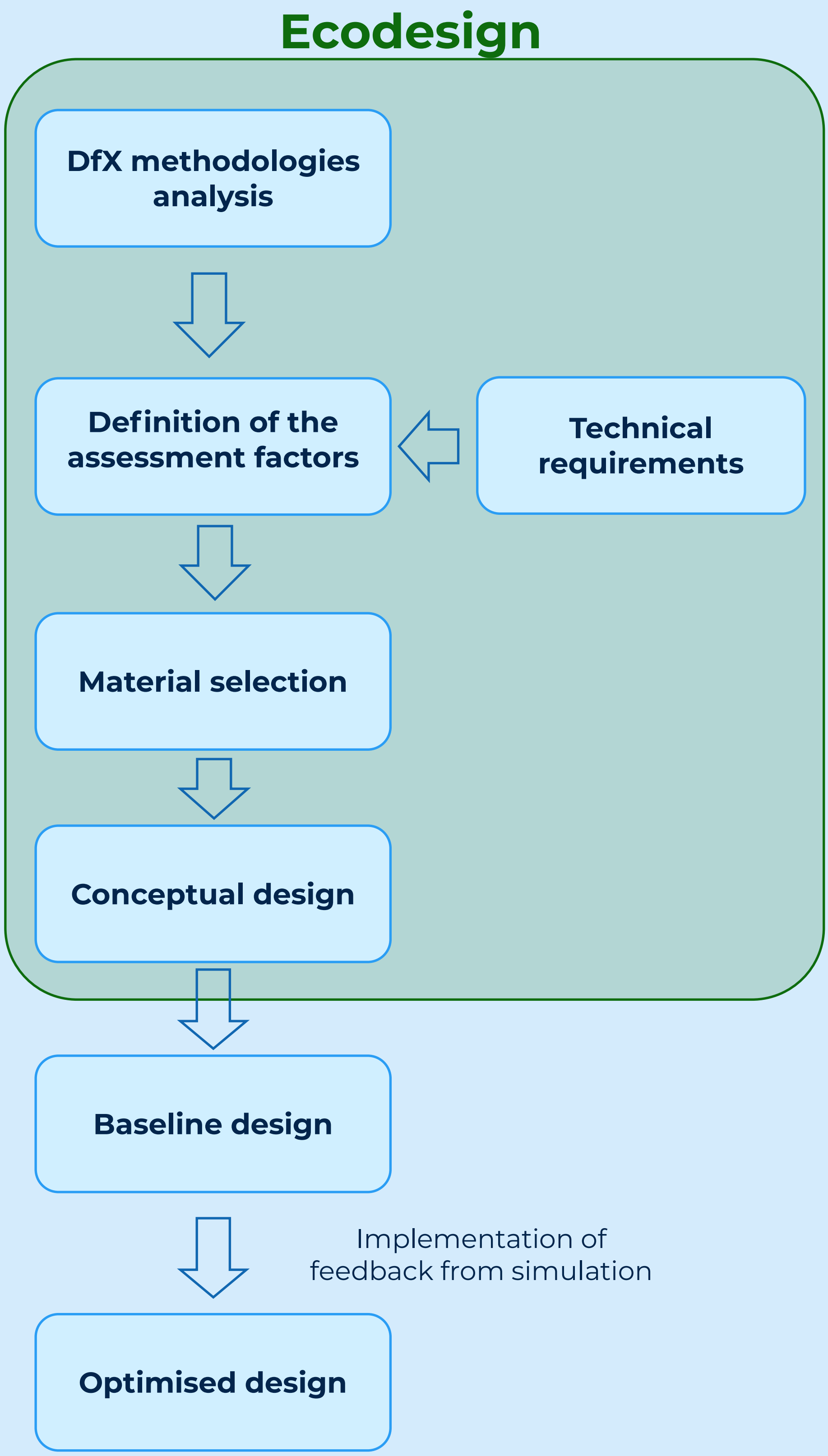

Figure 8: Redesign procedure applied in SALIENT.

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