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Environmentally Conscious Design (ECD) applied on a Radar System

Master's thesis in Industrial Design Engineering

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Gothenburg, Sweden 2026
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Master's Thesis 2026

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Master’s Thesis in Industrial and Material Science (IMSX30)

Environmentally Conscious Desing (ECD) applied on a Radar System

A User-centered Approach to Bridging the Gap Between Expert and Novice Operators

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Abstract

This study applied Saab's ECD methodology to the G1X radar system to identify critical areas for improvement and develop sustainable solutions. The research aimed to reduce environmental impact while considering the needs of manufacturing operators and ensuring product performance. The ECD methodology, combined with backcasting, was used to envision a sustainable future and work backward to identify necessary steps and initiatives. Key findings include the reduction of hazardous substances, minimization of adhesive use, and integration of two components to enhance efficiency and sustainability.

This study applied Saab's internal Environmentally Conscious Design (ECD) methodology to the Giraffe 1X (G1X) radar system to identify critical areas for environmental improvement and develop sustainable design solutions. Adopting a user-centered approach, the research aimed to reduce life-cycle environmental impacts while explicitly considering the ergonomic and operational needs of manufacturing operators and ensuring thorough product performance.

The ECD methodology, combined with backcasting principles, was used to envision a sustainable future for the radar system and work backward to identify necessary design initiatives, specifically focusing on the complex C1 component. Key findings from the assessment led to engineering design solutions that enable the reduction of hazardous substances, the minimization of chemical adhesive use, and the structural integration of components to enhance both assembly efficiency and end-of-life recyclability.

The proposed design concepts offer improved environmental, social, and economic sustainability. Ultimately, this thesis demonstrates a successful and practical implementation of the ECD methodology within a highly technical product development context, showcasing how strategic sustainability targets can be balanced with operational constraints in the production environment.

Keywords: Environmentally Conscious Design (ECD), Life Cycle Assessment (LCA), Sustainable Product Development (SPD), Radar Systems, User-Centered Design, Backcasting, Defense Industry.

Abbreviations

ECD – Environmentally Conscious Design
G1X – Giraffe 1X (radar system)
LCA – Life Cycle Assessment
SPD – Sustainable Product Development
FSSSD – Framework for Strategic Sustainable Development
EIA – Environmental Impact Assessment
PDM – Product Data Management (Saab's internal documentation system)
KJ (method) – A qualitative data analysis method used for clustering ideas
CAD – Computer-Aided Design
C1 – Component of the G1X radar system
C3 – Component of the G1X radar system
C1AA – Subcomponent within the C1
C1AI – Subcomponent within the C1
C1AJ – Subcomponent within the C1
FAME – Fatty Acid Methyl Esters
KPI – Key Performance Indicator

Acknowledgements

I would like to express my gratitude to my supervisor and examiner at Chalmers University of Technology, Pauline Leonard and Sophie Isaksson Hallstedt, for their guidance, support, and valuable feedback throughout this work.

I would also like to thank all the experts at Saab Surveillance who generously shared their knowledge, time, and insights, which were fundamental to the project. A special thank you goes to my supervisor at Saab, Mimmi Johansson, whose constant support, guidance, and assistance were essential throughout this thesis.

A very special thank you goes to my thesis partner during the first half of the project, Tova Johannesson, for the close collaboration and shared effort in conducting the litterature review and data collection and navigating the challenges of the early stages of the work. This thesis would not have been possible without the baseline we created together.

Finally, I would like to thank everyone whose support, patience, and encouragement motivated me throughout my thesis work and during the past five years of my studies.

With kind regards,
Tanja Svrabić

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1 Introduction

The manufacturing industry is undergoing a significant transition towards improved sustainability, driven by global targets such as the UN Sustainable Development Goals and the commitment to achieve net-zero emissions by 2050. Saab AB, a leading Swedish defense company, has set an ambition to become the most sustainable company within the defense sector. This study applies Saab's ECD methodology to one of Saab's products – the G1X radar system. The research aims to develop solutions that reduce environmental impact while considering the needs of manufacturing operators and ensuring product performance.

1.1 Background

1.1.1 Sustainability in the manufacturing industry

In response to global targets, such as the UN Sustainable Development Goals and the commitment to achieve net-zero emissions by 2050 (UNEP, 2025), the manufacturing industry is facing a significant transition towards improved sustainability. The sector must strive to develop solutions that reduce environmental impact, as it includes many high-emitting activities responsible for 25% of global carbon dioxide emissions (UN, 2023).

One company that has committed to this transition is Saab AB, a leading Swedish security and defense company, and collaborating company for this thesis project. Saab has set the ambition to become the most sustainable company within the defense sector (Saab AB, 2024). A goal that requires evolution of their engineering practices and design methodologies. As part of their efforts to work more systematically with sustainability, Saab is implementing their own version of Environmentally Conscious Design (ECD) methodology (Saab AB, 2024a), which will be applied in this study. The ECD analysis will be based on Life Cycle Assessment (LCA) data from a previous thesis (Berggren & Linderfalk, 2025). The main finding from their project is that the product's use-phase and maintenance phase account for the largest environmental impact. Consequently, this thesis will aim to find potential improvements primarily in those phases, but consider the other phases as well.

The G1X is operated and handled by humans, meaning that human factors will influence the interaction with the product. Therefore, it is crucial that any efforts to improve environmental sustainability do not degrade the social sustainability for the operator during the manufacturing phase, ensuring that principles such as ergonomics and usability are not compromised.

1.1.2 Radar systems and Giraffe1X

Conducted in collaboration with Saab Surveillance, this thesis focuses on the Giraffe 1X (G1X) surface radar system. The word radar comes from an acronym for Radio Detection and Ranging, meaning using electromagnetic waves to get information about a distant target (Bakare et al. 2022). The G1X system can be installed on a mobile or permanent structure and operated remotely or locally. The radar uses electromagnetic waves to detect, locate, track, and identify objects. It sends signals to the environment, and the signal bounces off the detected object and is received by the radar system. The radar system then provides needed information about the object such as location, velocity, and distance (Berggren & Linderfalk, 2025). The environmental impact of radar systems can be evaluated through methods like Life Cycle Assessment (Abshir & Larsson, 2025).

1.1.3 Sustainable design approaches and ECD

Integrating sustainability in product development can be complex, and experts may be experiencing difficulties when determining goals and scope for the project that will guide a more sustainable product (Schulte & Hallstedt, 2017). To support this, the Framework for Strategic Sustainable development (FSSD) has been applied and integrated into Sustainable Design tools. FSSD is well-known within strategic sustainable development and has been developed for over 20 years. Its purpose is to offer an understanding of the challenges with sustainability, as well as its opportunities, by providing a unifying structure (Broman & Robèrt, 2017). A core component of this framework is the defined overarching sustainability principles used from a backcasting perspective. Unlike traditional forecasting, which assumes current trends, backcasting envisions a successful sustainable future, and asks what strategic steps are required today to reach that state (Vergragt & Quist, 2011). By taking inspiration from this methodology, the project aims to facilitate Strategic Sustainable Development (SPD) within the design process of the G1X.

As previously stated, the Environment Conscious Design (ECD) method created by Saab will be applied to the product G1X. This is a methodology that integrates environmental aspects into product development by identifying improvement areas related to the product lifecycle and determining actions to implement through development work (Zhang, 1999). With the goal of using the outcome to reduce the environmental impact of products, this methodology can be considered as a part of Sustainable Product Development (SPD).

Sustainability approaches can be categorized as relative and absolute. A relative sustainability approach focuses on reducing the impact compared to a reference. (Hauschild et al., 2015). In contrast, the absolute sustainability approach sets goals and evaluates if the impact remains within them (Bjørn & Hauschild, 2013). The FSSD framework and the sustainability principles align with the absolute perspective and provide a definition of sustainability at the principal level. Its principles function as boundary conditions for strategic decision-making by clarifying which directions of development are incompatible with long-term sustainability. This theory provides relevant inspiration and support for achieving improved environmental outcomes.

1.2 Aim and RQ

The aim of this study is to apply the ECD methodology for complex products, like the G1X, within an industrial setting utilizing a life cycle perspective for environmental sustainability. Furthermore, this thesis investigates the design implications for manufacturing operators when improving a product's environmental performance based on results from this methodology, while maintaining the product's requirements, performance, and considering costs.

The following research questions are addressed in the study:

RQ1: How can the ECD methodology be applied to identify and prioritize environmentally critical improvement areas in a complex product like the G1X?
RQ2: How can identified improvement areas be used to improve existing product design that reduce environmental impact without compromising social sustainability for manufacturing operators, product performance and functional requirements?

1.3 Objectives

The objective of the thesis is to apply the ECD methodology to a case product at Saab to identify environmentally critical improvement areas and translate these into design solutions that reduce environmental impact while considering manufacturing operators and meeting the product requirements and performance. In more detail, this means that the study will:

1. Apply the ECD methodology to the G1X using existing LCA data along with newly collected data.
2. Analyze and select main area(s) of improvements based on the ECD analysis.
3. Identify problems and user needs for manufacturing operators within the selected improvement areas.
4. Develop a conceptual design proposal that balances a user-focused perspective with a reduced environmental impact.
5. Estimate and verify the potential environmental impact reduction of the proposed concept compared to the reference product.

1.4 Limitations

At the outset of the study, data gathering is initiated. This includes the LCA performed at Saab. This will be an inventory of current knowledge. Some additional information may need to be collected to be able to perform the ECD. The level of detail will be determined once the known and unknown factors have been clearly identified.
This study uses data from an LCA conducted in a previous thesis. The scope of that analysis was restricted to one component, rather than evaluating the entire G1X system (Berggren & Linderfalk, 2025). To ensure data consistency and validity, this thesis adopts the same delimitation.

Due to time constraints of the project, the concept development phase will focus on a selected subsystem or 'hotspot' identified using the ECD method. The number of areas/criteria/hotspots to work with is flexible and depends on the time available. No cost analysis will be carried out, rather a focus on environmental improvement will take place. Furthermore, the study focuses on mechanical design and material selection. Electronics and software are excluded unless they are directly affected by mechanical choices.

The deliverables include a conceptual design, and the concept will be presented in the form of visualizations and sketches, not a manufacturing-ready blueprint. This could be done through CAD models or illustrations made by hand. This decision will depend on the time available and how much value it would bring.

To explore if the developed concept has been improved compared to the original product, a verification analysis will be made. This is a necessary step and follows the ECD methodology of Saab. However, no complete new LCA will be performed for the new concept. The verification will focus on environmental improvements and will be estimated through simple comparisons, e.g., based on material and weight differences. The study does not include functional testing of the developed concepts, but product performance is included during concept development.

1.5 Social, ethical and ecological aspects

Social, ethical, and ecological aspects have been evaluated to ensure a comprehensive perspective. We have identified the following as key considerations.

Ethical aspects

To be able to review and re-design the surface radar system G1X, it is essential that all Saabs internal data is handled in accordance with data security protocols and confidentiality agreements. Anything else could result in serious consequences and affect the entire company.

Furthermore, it is important that all data sources used are reliable, transparent, and well documented to make well-founded decisions. If not followed, it carries the risk of decision-making based on faulty data. This could not only affect the validity of the project's results but, in the event of implementation, it also negatively impacts the final product and the company itself.

Beyond data security, the project involves several other considerations. An important ethical aspect is balancing stakeholder requirements. As engineers, there is a responsibility towards the product owner to deliver a feasible and cost-effective design. At the same time, there is an ethical responsibility towards the environment to maximize the reduction of the product's ecological footprint. Furthermore, from an academic perspective, there is a duty to evaluate the ECD method objectively, regardless of whether the outcome favors the company or not.

Another ethical concern is the limitations made to focus on mechanical design. This may exclude areas with high environmental impacts. However, this was necessary to ensure high quality of the solutions proposed.

Social aspects

In a broader context, this thesis aligns with the 16th sustainable development goal: Peace, justice, and strong institutions. Therefore, we are working on the premise that security is an important condition for a sustainable society.

Another aspect concerns human-machine interaction. The product, G1X, is operated in high stress levels where reliability is crucial. Any design changes proposed to improve sustainability must not compromise the safety, ergonomics, or usability for the operator. A product with lower environmental impact that fails in the operating environment is not a socially sustainable solution.

Ecological aspects

The ecological objective is to lower the environmental footprint of the product through the application of the ECD methodology and through informed design choices. The work has a lifecycle perspective to ensure that environmental problems are not shifted from one phase to another. Ecological aspects that will guide the concept development include resource efficiency, circularity, and impact reduction.

Throughout the study, social, ethical, and ecological aspects will be continuously weighed against each other to ensure a holistic and responsible design proposal.

2 Method

This study was conducted in three main phases: (1) Literature review, (2) ECD application, and (3) Product development (see Figure 1).

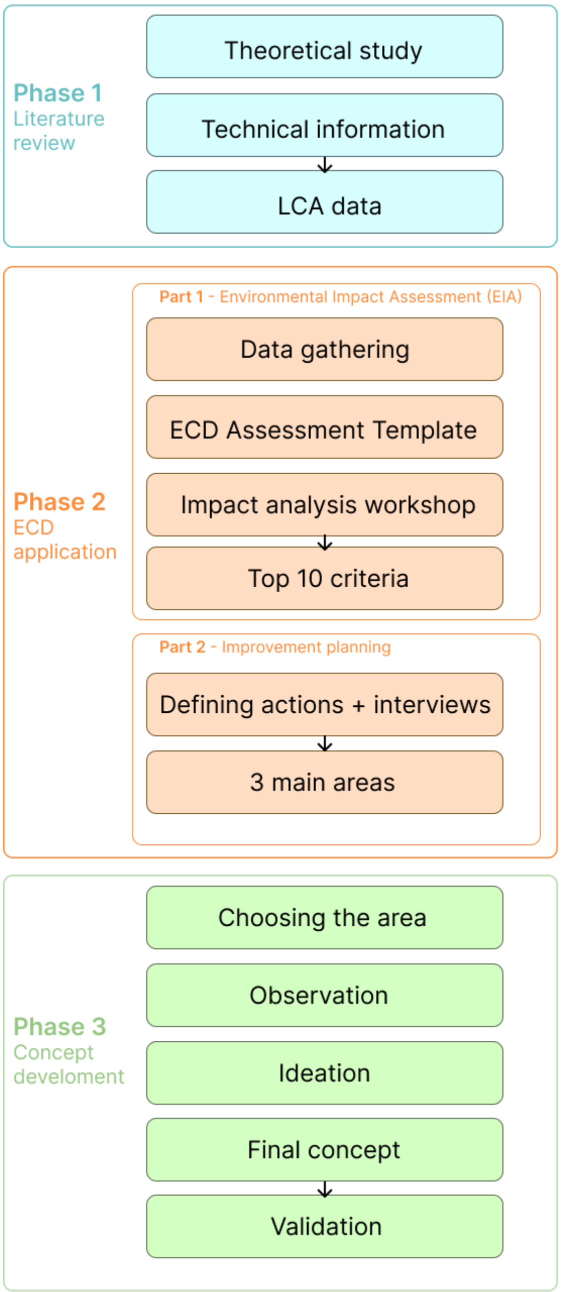


Figure 1: Method phases

2.1 Phase 1 – Literature review

This phase consisted of a literature review divided into two parts: theoretical framework and technical background. The purpose was to build the necessary theoretical and technical foundation for the study.

2.1.1 Theoretical framework

Academic articles were reviewed to establish a framework within sustainable product development, sustainable design, Environmentally Conscious Design (ECD), and the Framework for Strategic Sustainable Development (FSSD). This provided the theoretical basis for understanding, selecting, and practically implementing the methods used in this thesis.

2.1.2 Technical background

The technical background was based on Saab's internal reports, including the previous master's theses with the LCA report, G1X documentation, and the ECD methodology. Additional literature on radar technology and sustainability, together with internal documents, company support, provided further context and understanding of the G1X system.

2.2 Phase 2 – ECD application

This phase focuses on applying the ECD methodology to the G1X product using Saab's internal ECD template, which served as a framework for analysis. The scope included part C1 and its subcomponents (see Figure 2), while other parts were excluded due to complexity and relevance boundaries. The process consisted of two parts: Environmental Impact Assessment (EIA) and Improvement planning.

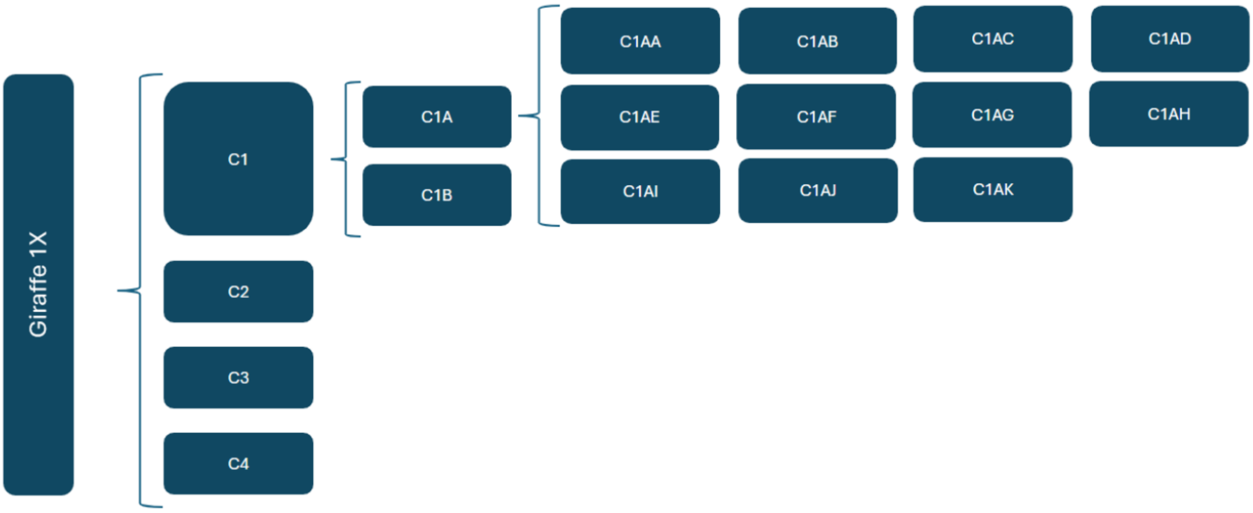


Figure 2: The component tree of G1X – the scope included the component C1

The purpose of this phase is to apply the ECD methodology and identify environmentally critical areas and their improvement. This was made through data gathering, Impact analysis workshop and planning the improvement actions.

2.2.1 Part 1 – EIA (Environmental Impact Assessment)

Data gathering

To structure the assessment, the baseline LCA report (Berggren & Linderfalk, 2025) was analyzed together with Saab's ECD template, which consisted of 40 criteria grouped according to the product life cycle stages. A material engineer supported the review and prioritization of the criteria, and all collected data were documented in the ECD template. Prior to the Impact Analysis workshop, the criteria were restructured and merged to reduce complexity and facilitate the assessment process.

Impact analysis Workshop

A cross-functional, two-hour workshop was conducted with nine internal experts together with a facilitator and note-taker (see Table 1), to evaluate the product's improvement potential. The workshop included representatives from design, materials, and environment. Representatives from production and logistics and packaging were invited but unable to attend.

Table 1: Workshop participants

Material engineer
Material team leader
Material engineer
CAD design engineer
Engineer manager
Systems engineer
Environmental coordinator
Facilitator
Note-taker

- *Visioning (Backcasting):* The workshop began with a 10-minute brainstorming session where participants used guiding questions (adapted from Schulte & Hallstedt, 2018) to envision a sustainable version of the G1X using post-it notes. This established a shared, long-term vision. To assist this process, the following guiding questions were used:
    - What are the materials to be used in a sustainable product version?
    - Which suppliers are associated with a sustainable product? (e.g. working conditions)
    - How could a sustainable product be produced? How are the working conditions? Consider e.g. chemicals, health and safety, emissions to air, water and soil
    - How is the sustainable product used and maintained? (e.g. life-time, noise, secure/robust design)
    - How can the product be recycled, resued, re-manufactured for a prolonged lifespan?

- *Assessment process:* Participants evaluated the restructured criteria list by reaching a consensus on whether improvements were possible ("Yes/No"), see Figure 3 for an example. The responses were entered into the ECD template, which automatically calculated a top 10 prioritized list of criteria.

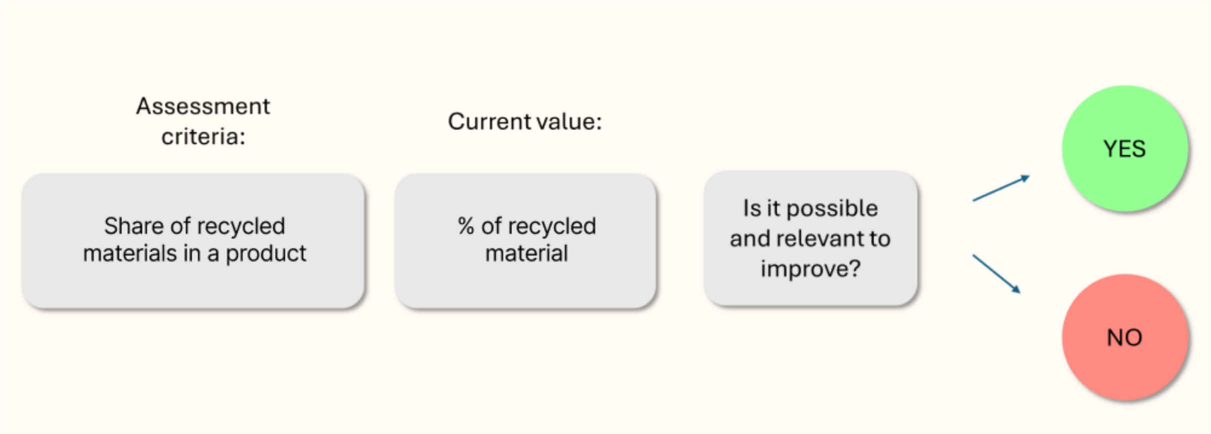


Figure 3: Example of the impact analysis

Survey

Directly after the workshop, a 5-minute survey containing seven open-ended questions was distributed to the six expert participants to gather feedback on the backcasting process, method complexity, and the utility of the ECD framework. These were the questions asked:

1) Did you feel that the Backcasting(visioning) at the beginning made it easier to see long-term solutions?
2) What was the biggest challenge with using this method today? (Both ECD criteria and Backcasting)
3) On a scale of 1 (not likely) – 5 (very likely), how likely is it that you would want to use this way of working again?
4) Was there any moment you found valuable for identifying improvements? If yes, which one?
5) Was there anything in the ECD methodology itself that felt complicated to understand?
6) Do you believe that this way of working will lead to actual improvements for SAAB?
7) Do you have any other feedback or final thoughts for us?

Data analysis (KJ method and Workshop evaluation)

The qualitative data and ideas from the workshop were clustered using the KJ method to synthesize environmental hotspots. The workshop process was evaluated to ensure data validity. Finally, the template scoring system was analyzed to explore different variations of the top 10-list before selecting the final version for further development.

2.2.2 Part 2 – Improvement planning

The purpose of this stage was to define, scope, and validate concrete improvement actions for the prioritized criteria. Based on the outcome of Part 1 - EIA, the most critical improvement areas (top 10 criteria) were prioritised for further development. For each selected criteria, actions were defined.

Defining actions and scoping

Potential actions were generated by combining ideas from the workshop's KJ analysis, secondary research, and a brainstorming session into a matrix. To keep the project scope manageable, criteria were excluded or combined based on the availability of relevant information and the feasibility of the generated actions. This list served as the basis for follow-up interviews, where the proposed actions were discussed, evaluated, and complemented with additional improvement ideas.

Follow up interviews

To further explore the identified environmental hotspots and define improvement opportunities, two semi-structured follow-up interviews were conducted using a backcasting (visioning) approach. The discussions began with a review of the top 10 criteria and visioning questions, such as: *“What do we want to achieve with this change?”* and *“What is our dream scenario?”*

- Material sourcing: The first interview was conducted in a group interview with three material engineers to detail actions regarding material choice and supply.

- Assembling: An interview with an assembly operator to identify practical assembly challenges and potential improvements.

2.3 Phase 3 - Concept development

This phase involved re-designing the product based on the analytical results from Phase 2 – ECD application. Due to the product's technical complexity, it was executed in close collaboration with Saab’s experts through an iterative process of definition, ideation, and validation.

2.3.1 Problem definition and scoping

- *Choosing an improvement area:* An improvement area was selected from the hotspots identified in Phase 2 – ECD application, based on its improvement potential, feasibility within industrial design engineering, and expert insights.

- *Translating actions into requirements:* In accordance with the ECD methodology, the defined improvement actions for the chosen area were translated into concrete design requirements and project objectives.

2.3.2 Observation

To establish a clear problem definition, an observation was conducted within Saab Surveillance’s production department. An operator was observed and interviewed using structured guiding questions to map user needs, ergonomics, and practical challenges. Key steps of the process were documented through sketches. To ensure continuous feedback, this baseline was supplemented by subsequent meetings and production visits with technicians and operators throughout the defining, ideation, and final concept stages.

2.3.3 Defining requirements

Data from the observations, internal documents, and engineering meetings were synthesized into three structured requirement lists to serve as a baseline for development:

- *User problems and needs:* Concrete operator and ergonomic challenges were identified and combined with follow-up interview insights to establish a definitive list of user requirements. The user was the manufacturing operator.
- *Product requirements:* Technical and mechanical boundaries, such as allowable component modifications (e.g., structural drilling boundaries), were mapped and documented through consultations with a CAD engineer.

- *Design concept requirements*: A synthesis of user needs and product constraints defining the core technical functions, project aim, and specific category scope.

2.3.4 Ideation

To generate a broad set of solutions, three iterative ideation rounds were conducted using brainstorming, brainwriting, and braindrawing. Concepts were visualized via manual sketches and continuously refined through technical feedback loops:

- *Ideation 1:* Initial conceptual sketching based on memory and basic product layouts to establish preliminary design directions.

- *Ideation 2:* Refined sketching incorporating direct feedback from production operators regarding components handling.

- *Ideation 3:* Detailed sketching evaluated during product observation with technicians to assess practical implementation potential.

2.3.5 Final concept

The development of the final concept began with a third ideation round, after which the most promising concept was selected through evaluation and further developed and visualized.

- *Concept evaluation:* The generated concepts were evaluated against a digital CAD model with a CAD engineer to discard unfeasible ideas. Remaining options were reviewed with a design manager, a design engineer, and a general engineer to evaluate production feasibility and select the concept with the highest potential.
- *Component data:* Technical data and measurements were gathered from Saab's PDM system alongside physical measurements (e.g., component weight) to support detailed design decisions.
- *Visualisation:* The final adjustments were made and the measurements were decided. The final concept was visualized through sketches.
- *ECD criteria mapping:* The design was then mapped against the original criteria identified in Phase 2 - ECD application, to demonstrate how it mitigates the targeted environmental impacts.

2.3.6 Validation

The final concept was validated through stakeholder discussions from environmental, technical, and practical perspectives. Rather than reapplying the full ECD template, a trade-off analysis was conducted to assess the balance of added versus reduced impacts within the product system. Unquantifiable complexities were documented as recommendations for future development.
The evaluation framework validated the concept across five specific pillars:

- Material environmental impact
- Costs
- Product performance and quality
- Time aspect
- Social sustainability

3 Results

3.1 Phase 1 – Literature review

This section presents the theoretical and technical foundation used to analyse and generate the study's results. The theoretical framework (3.1.1) outlines the EcoDesign principles and Saab's methodology used to evaluate the outcomes, while the technical background (3.1.2) introduces the G1X radar system and its baseline LCA data. Together, they form the analytical lens for identifying and evaluating pathways for environmental improvement.

3.1.1 Theoretical framework

Sustainability

There are many definitions to the concept of sustainability. One of the most used origins from the United Nations Brundtland Commission who defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development [WCED], 1987). Another way to describe sustainable development is through the three dimensions of sustainability. This framework states that to be sustainable, you must address these three equally important parts: the environment, the social, and the economic (FN, 2023), see Figure 4. However, sustainable development is commonly related to trade-offs. For example, achieving increased environmental performance often conflicts with the goal of maintaining the lowest cost (Baard et al., 2011). These three pillars form the foundation of the UN Sustainability Goals in Agenda 2030. This is a plan of action, consisting of 17 goals, designed to create a sustainable society for the planet, its people, and its prosperity by 2030 (FN, 2023).

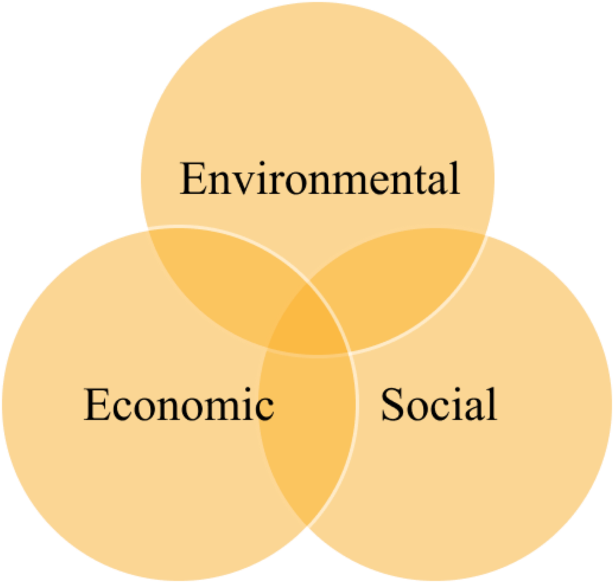


Figure 4: The three dimensions of sustainability

This view on sustainability is also known as the triple bottom line, a term created by John Elkington (Elkington, 1997). However, since the environment is the foundation of all sustainability, the concept of sustainability can be viewed in another way, namely as nested circles (see Figure 5). The social dimension then exists entirely within the environment. And the economy is a bi product of society. Instead of three overlapping circles, we have three nested circles (Schulte & Knuts, 2022). The framework for strategic sustainable development (FSSD) shares this nested view on sustainability (Schulte & Knuts, 2022).

The framework for strategic sustainable development (FSSD) is a well-known model that helps organizations move towards sustainability by using a 5-step hierarchy: system, success, strategic guideline, actions, and tools. This framework guides organizations from understanding global systems to taking practical, sustainable actions. At its core, the framework defines a "success" through eight sustainability principles and uses a method called "backcasting" (Broman & Robèrt, 2017). This is a method of planning backwards from an ideal, desirable, and sustainably future. By looking back from the future to the present, organizations can understand their current situation and identify the exact steps needed to get there. This ensures that every decision made today serves long-term sustainability (Dreborg, 1996; Quist et al., 2011; Robinson, 1990; Vergragt & Quist, 2011).

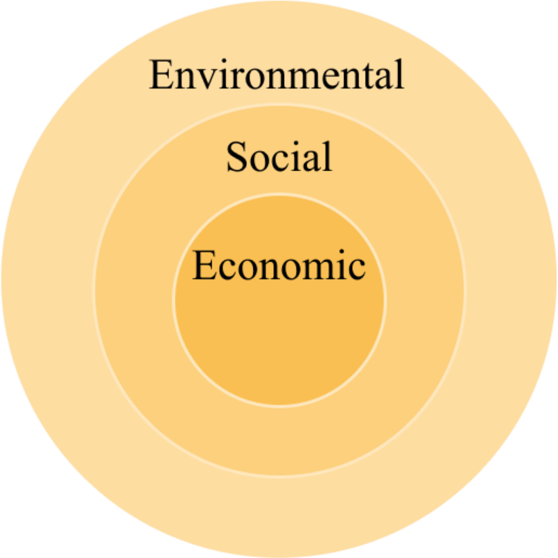


Figure 5: Sustainability viewed as interdependent dimensions.

Sustainable product development (SPD)

According to Baldassarre et al. (2020), sustainable development can be seen as "the rational and structured process to create something new for solving sustainability-related problems". This problem-solving approach is implemented through Sustainable Product Development (SPD). Sustainable product development, also known as sustainable design, is when sustainability is integrated into the entire life cycle of a product, system or solution and is considered in the early stages of a design process (Design Society, 2023). According to Hallstedt et al. (2023) integrating sustainability aspects into product development means: (i) developing solutions that utilise technologies new to the company and the market, with a high sustainability potential; (ii) developing business models and solutions that cover the entire product life cycle – from material acquisition to end of life, and consider all stakeholders and actors within this value chain; (iii) managing and mitigating the risk associated with new technologies and new business models.

Sustainable design is not a new concept. In fact, methods and tools to support this have been developed for the last 35 years and has been a topic of discussion for the last 50 years. There are hundreds of sustainable design methods and tools available today, yet the uptake by the industry is low. There are several reasons for this. Firstly, there is a lack of awareness regarding academic developments and a general shortage of resources, such as eco design competency and financial investment, for practical implementation. Furthermore, companies often find it difficult to translate sustainable initiatives into business value. Organizational culture also influences this, as many firms prefer developing in-house solutions over adopting external tools (Faludi et al., 2020).

The design of the tools themselves plays a role in the applicability; adoption depends on how user-friendly the method is, how time-consuming it is, the ease of learning it, and whether it delivers clear guidance for the organization. A major challenge for sustainable design is that it is often associated with additional costs. When sustainable methods generate economic profit, they tend to be redefined as business development or efficiency improvement, which leaves behind a misleading image of sustainability as an economic burden. Therefore, it is mainly "low-hanging fruit" with clear economic advantages that achieves widespread implementation in industry (Faludi et al., 2020).

EcoDesign and Environmentally Conscious Design (ECD)

The terms Eco design and Environmentally Conscious Design (ECD) are often used synonymously (McAloone, 1998). This is because both focus on incorporating environmental considerations into the design process, with the goal of reducing environmental impact through better design through the entire product life cycle (Ds 2007:15, 2; McAloone, 1998), see Figure 6. Practical applications include optimizing function, material selection, and production, as well as maximizing lifespan and recyclability (Norrblom et al., 2000, p. 10**).** Environmental performance is part of the properties of a product, and the ecological impact should be weighed equally against traditional key parameters, such as profitability, quality, and functionality (Design Society, n.d.; Norrblom et al., 2000, p. 10). Consequently, environmental requirements must be integrated during the earliest stages of the design process. This is because the ability to influence a product's environmental profile is greatest at the outset; as the project progresses, design freedom decreases while the cost of changes increases (Luttropp & Lagerstedt, 2006).

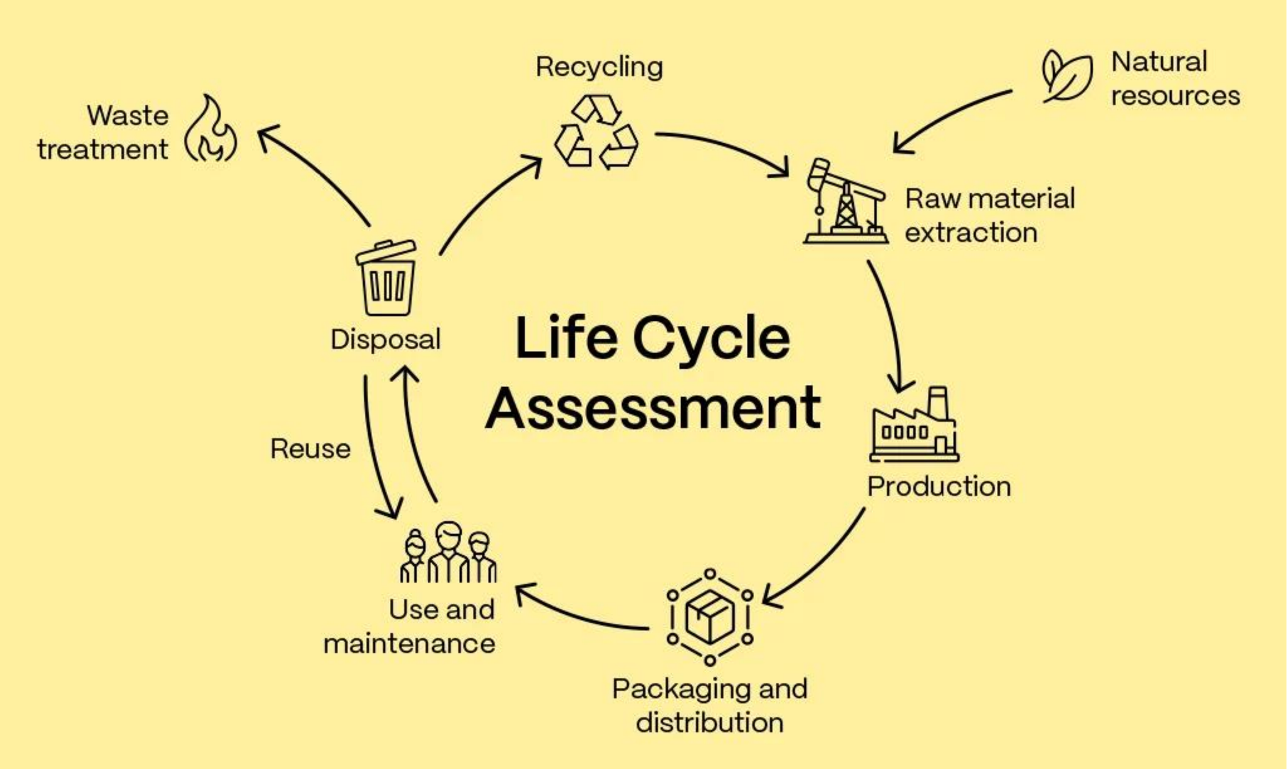


Figure 6: Schematic lifecycle (Source: Swiss Federal Office for the Environment (BAFU), 2022)

When implementing Environmentally Conscious Design or EcoDesign, two parts are usually present: environmental assessment and environmental improvement. The objective of the environmental assessment is to understand and evaluate how a product, service, or solution performs from an environmental perspective across its life cycle. The assessment aims to highlight environmental hotspots and provide a basis for improvements to reduce environmental impact. The second part, environmental improvement, focuses on finding solutions with improved environmental performance (Vallet et al., 2013).

Environmental assessment

Life Cycle Assessment (LCA) may be the most well-known EcoDesign tool and is used to analyse and assess all aspects of a product or solutions for sustainability performance through its life cycle (Norrblom et al., 2000, p. 40). According to Hallstedt et al. (2023), LCA tools are one of the two most discussed methods for the sustainability assessment of products. The other one is multi-criteria decision models (MCDM), also known as multi-attribute decision models (MADM). These models often combine LCA with other analytical tools. They do this because LCA alone often focuses strictly on environmental data, whereas MCDM allows researchers to integrate qualitative factors and handle trade-offs between competing priorities, such as cost versus environmental impact (Isaksson Hallstedt et al., 2023). However, even with these tools, assessing the environmental performance of a product is complicated and companies struggle with performing these assessments in an efficient way. A reason for this is their varying interpretations of sustainability, leading to a lack of consensus (Schulte & Hallstedt, 2017).

Environmental improvement

Beyond the assessment, the second part of eco-design focuses on creating environmental improvements. This means identifying and developing concepts that are "better" from a sustainability perspective. This generative process is similar to standard product development practices. Idea generation methods which may be used are brainstorming, brain drawing, brain writing, or morphological box. Once that phase is complete, concepts may be developed, evolved, and combined to achieve environmental improvement and business value (Vallet et al., 2013).

Concept development

According to Ulrich and Eppinger (2012, pp. 44, 168), a concept is a description of a products form, function and specifications, often in the shape of a sketch or 3-dimensional model. It illustrates how the product will satisfy the needs. Once the needs and specifications are identified, the process of concept generation begins. This is an iterative approach where existing solutions and new ideas are explored.

A major argument for focusing on this early in a project is because it is far more cost effective to explore different paths and make changes during the concept stage than to fix issues later in the However, this concept had a thinner structure and used less material. development process (Ulrich & Eppinger, 2012, p. 168). This is similar to the principles of Environmentally Conscious Design mentioned earlier. Since design freedom is at its peak and the cost of changes is at its lowest, this is the most critical window for integrating sustainability.

Saab's ECD methodology

Saab has developed their own version of ECD methodology. It is a systematic approach to support the company to integrate environmental aspects into product design development. This approach works on all life cycle stages of a product through several sustainability criteria and in that way identifies, evaluates and improves the environmental performance of products. Through combining environmental assessment and environmental improvement, the purpose of this method is to support integration of sustainability into the early design stages to end-of-life stage. ECD aims to minimize environmental impact of products and address trade-offs between important product aspects such as durability, cost and safety (Saab, 2025).

Other methods and tools (inside FSSD)

Several methods within SPD and FSSD aim to support long-term sustainability in product development. Traditional sustainability tools often lack a future-oriented perspective, limiting proactive decision-making (Hallstedt et al., 2013). Therefore, methods such as Strategic Sustainability Assessment (SSA), SPD workshops, and Sustainability Design Space (SDS) apply backcasting and life cycle thinking to guide companies toward sustainable solutions. The following methods and tools have been applied in various studies to examine their implementation and effectiveness in companies and academic groups.

Environmental Impact Assessment (EIA) and Strategic Sustainability Assessment (SSA)

Environmental Impact Assessment (EIA) was combined with Strategic Sustainability Assessment (SSA) in a study to evaluate a jet engine component. While EIA identified environmental "hot spots," it was considered insufficient on its own. SSA complemented the analysis by using guiding questions to analyse broader long-term sustainability consequences. SSA was inspired by the Method for Sustainable Product Development (MSPD) (Byggeth et al., 2007).

Sustainable product design (SPD) workshop

Similarly, the SPD workshop used backcasting to support teams in sustainable product development, utilitising backcasting in three steps: create a vision of a sustainable product, assess the current situation, and identify strategies for improvement. The method supported sustainability discussions in early design phases but depended strongly on participants' expertise (Schulte & Hallstedt, 2017).

Sustainability Design Space Approach (SDS)

In the study by Watz & Hallstedt, the SDS approach was applied to define long-term sustainability criteria and design guidelines. SDS helped teams better understand sustainability issues and identify relevant actions during product development. Using a backcasting approach, it starts from a desired sustainable future to identify which materials, process and activities to aim for or avoid (Watz & Hallstedt, 2021).

A common feature of all three approaches is the use of backcasting and long-term sustainability goals. By creating a sustainable future vision, the methods provide strategic direction, improve understanding of sustainability challenges, and support more proactive decision-making in product development.

3.1.2 Technical background

Radar system

The radar system G1X (Figure 7) was developed in 2014 and is part of the Giraffe radar family originally introduced in 1977 by SAAB AB (SAAB AB, 2025b). It belongs to the ground-based air defense domain and is designed to detect, locate, track, and identify objects in the air.

The system works by using electromagnetic waves. The radar sends signals into the environment, and when these signals hit an object, they bounce back toward the radar. The returned signals are then received and processed by the radar system, which provides information about the detected object, such as its location, velocity, and distance. (Echodyne, 2025).

Figure 7: Radar system G1X (C1 component)

The radar weighs about 150 kg and can be installed either on mobile platforms or on permanent structures. It can also be operated remotely or locally depending on the operational requirements (SAAB AB, 2025a). In addition to military applications, the system can be used for civil purposes, such as protecting large public events or monitoring flight zones around airports. The system consists mainly of the components C1 and C3 (Berggren & Linderfalk, 2025).

Conducted LCA on G1X

This thesis builds on a previously conducted LCA analysis that was carried out as part of another master's thesis project. The data from this analysis is mainly used in the Environmental Impact Assessment (EIA) stage of the ECD methodology to fill in missing information in the ECD template.

The study performed an LCA to evaluate the environmental impact of the G1X radar system throughout its life cycle. Data was collected from Saab's internal systems, material declarations, and CAD drawings, and emission factors were obtained from the Ecoinvent 3.11 database. An attributional LCA approach was used, with a cut-off method for recycling. The analysis included five life cycle phases: manufacturing, use, maintenance, transportation, and end-of-life. Environmental impacts were assessed using the ReCiPe 2016 methodology, focusing on six main categories: global warming, land use, terrestrial ecotoxicity, non-carcinogenic human toxicity, mineral resource use, and ionizing radiation. Different operational scenarios were also analyzed, including mobile, fixed, and maritime configurations, as well as wartime, training, and peacetime operations. A Monte Carlo analysis and sensitivity analysis were performed to evaluate uncertainties and the influence of parameters such as radar operating time, fuel choice, failure rate, and component replacement (Berggren & Linderfalk, 2025).

The results show that the use phase is the largest contributor to the radar system's environmental impact, mainly due to energy consumption and vehicle fuel use during operation. Maintenance has also a significant impact, largely because of the "repair-by-replace" strategy where subcomponents are frequently replaced. Over a ten-year period, some subcomponents may be replaced between about 6 and 22 times depending on the operational environment. Three major subcomponents (C1AA, C1AJ, and C3) account for more than 80% of the cradle-to-gate environmental impact due to their material composition and maintenance requirements. Sensitivity analysis also showed that replacing diesel with FAME biofuel could reduce environmental impacts in most categories. Overall, the results highlight that operational conditions, maintenance strategies, and fuel choice strongly influence the radar system's environmental footprint (Berggren & Linderfalk, 2025).

3.2 Phase 2 – ECD application

Based on the findings from the literature review, backcasting was integrated in the ECD methodology by providing a broader, vision-driven perspective on environmental improvements. This was inspired by a statement that relying mainly on one initiative can result in a limited and narrow contribution to sustainability, with limited coverage of the company's system (Hallstedt et al., 2013b). Figure 8 illustrates how backcasting was integrated throughout the different phases of the process. Figure 9 demonstrates the timeline of the activities and outcomes in this phase.

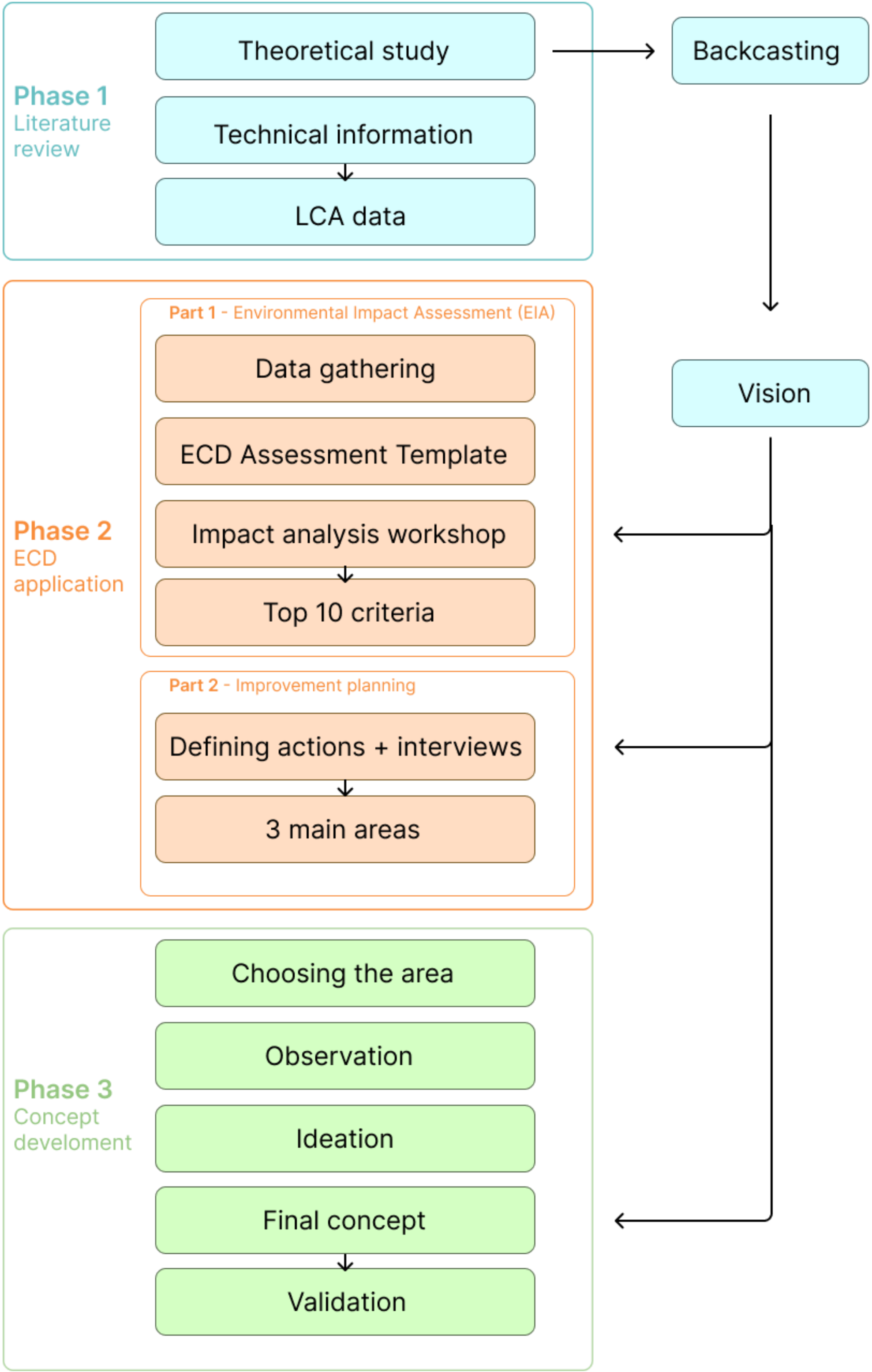


Figure 8: Integrating backcasting into the method phases

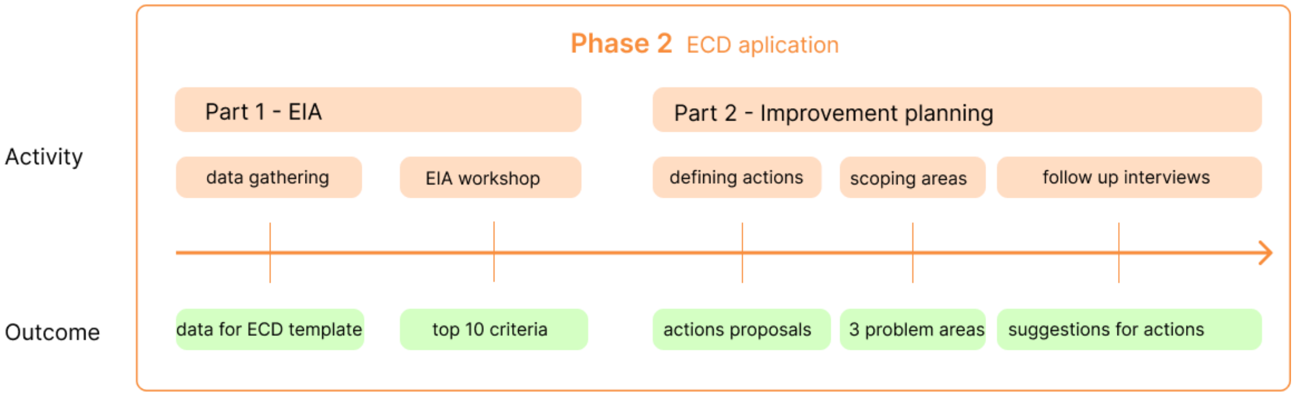


Figure 9: Timeline of activities and outcomes of Phase 2 - ECD applicaton

3.2.1 Part 1 – EIA

Data gathering

The review of the criteria resulted in conclusion to exclude seven criteria due to their complexity or irrelevance. The excluded criteria were not relevant to industrial design or out of scope, a criteria that focused on the materials that are used on the product during the maintenance phase, e.g. consumables such as materials for machinery maintenance. That was irrelevant for this project, since the scope included only the material used in the product. The remaining 33 criteria remained in the scope for further work.

The data sources were systematically organized into specific categories. Some criteria were extracted from the baseline LCA, whereas others required direct consultation with material and CAD engineers. For criteria dependent on chemical or material compositions, internal documentation, such as material declarations, was utilised. Once these categories were firmly established, the empirical data gathering was initiated.

The categories (or design focus areas) in ECD template were divided into life-cycle stages:

1. Design for material sourcing (criteria 1-10)
2. Design for manufacturing (criteria 11-16)
3. Design for transport and distribution (criteria 18-24)
4. Design for use and maintenance (criteria 25-32)
5. Design for end-of-life (criteria 34-40)

The ECD assessment template consisted of 40 criteria, and each criteria had its own assessment criteria that defined what it meant and required. The relevant Key Performance Indicator (KPI) was the type of data needed. Under “Available current/ reference value”, the answer was written using the gathered data. For example, the “Design for material sourcing” area consisted of several criteria for the materials. An example criteria in the ECD template is shown in Table 2 below.

Table 2: Example criteria in ECD template

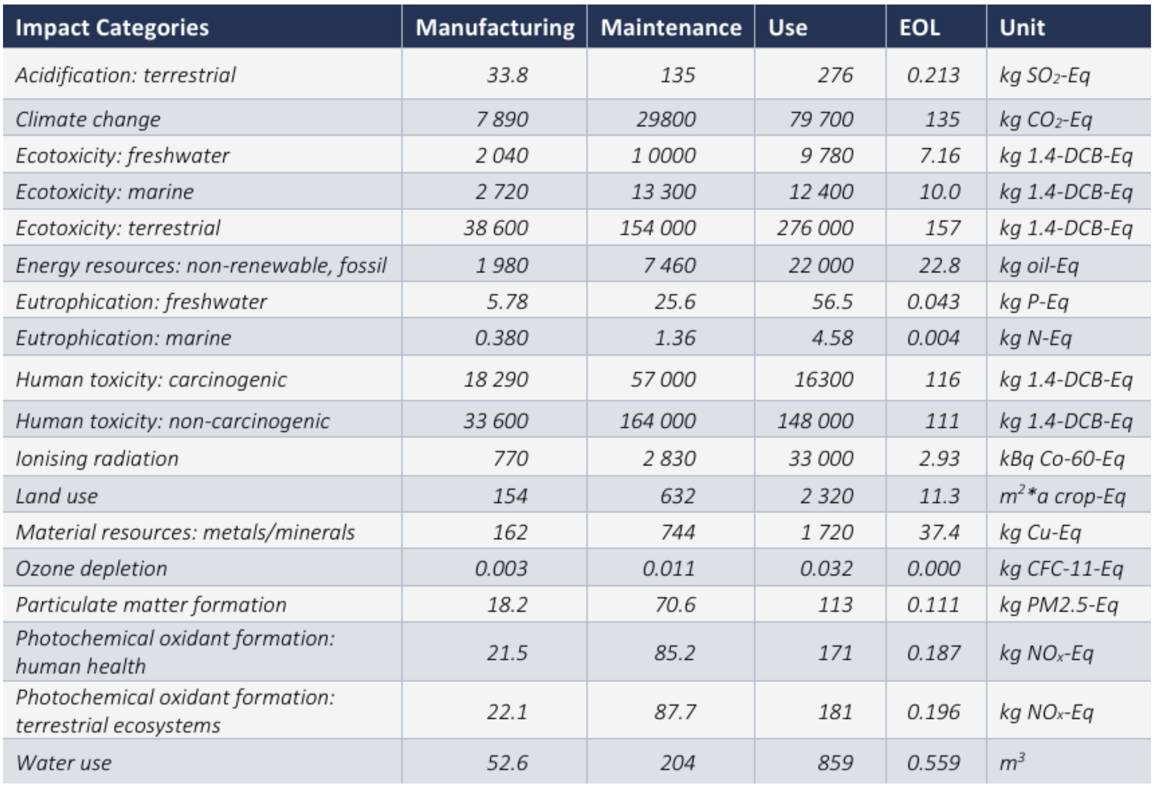
Design focus area	**Assessment criteria**	**Relevant KPI**	**Do we have a measured value today? (Y/N)**	**Available current/ reference value**
Design for material sourcing	Share of recycled materials in a product	%recycled material	Y	30 % of the component

LCA data

A substantial portion of the data required for the ECD criteria was extracted directly from the LCA results. However, certain data points needed adjustments, such as technical calculations and unit conversions, to properly align with the criteria assessment framework. For instance, these adjustments involved converting energy values into kilowatt-hours (kWh) and material mass into kilograms (kg). The primary categories where the LCA data provided these inputs were the use phase and the manufacturing phase.

The LCA report included several types of radar. In this thesis, the focus was on a land-based radar. The chosen scenario was an operational scenario – peacetime. The data provided from the conducted LCA was presented in an Excel document and it was divided into phases: maintenance & use, manufacturing and end-of-life. Each phase was divided into Impact categories, and these were used in this thesis: Climate change, Ecotoxicity (freshwater, marine, terrestrial), energy resources (non-renewable, fossil), water use, material resource use (see Table 3). The use and maintenance had the biggest impact due to the results from the LCA report, and these life cycle stages got bigger attention in the data gathering step of the Phase 2 – ECD application.

Table 3: Example of LCA data



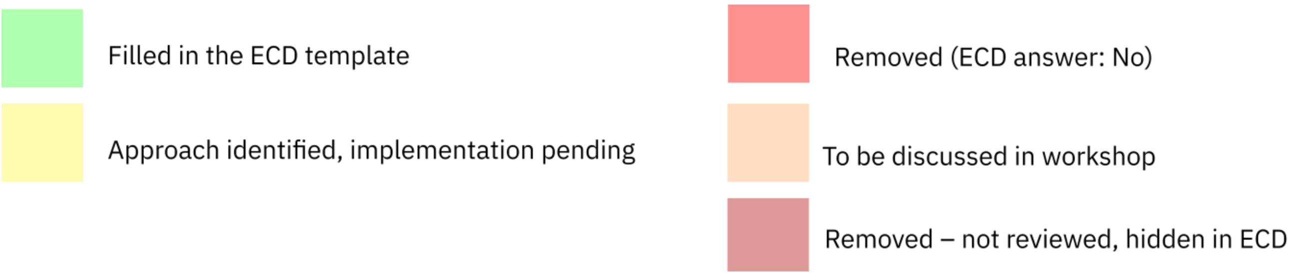
Impact Categories	Manufacturing	Maintenance	Use	EOL	Unit
Acidification: terrestrial	*33.8*	*135*	*276*	*0.213*	*kg SO_2-Eq*
Climate change	*7 890*	*29800*	*79 700*	*135*	*kg CO_2-Eq*
Ecotoxicity: freshwater	*2 040*	*1 0000*	*9 780*	*7.16*	*kg 1.4-DCB-Eq*
Ecotoxicity: marine	*2 720*	*13 300*	*12 400*	*10.0*	*kg 1.4-DCB-Eq*
Ecotoxicity: terrestrial	*38 600*	*154 000*	*276 000*	*157*	*kg 1.4-DCB-Eq*
Energy resources: non-renewable, fossil	*1 980*	*7 460*	*22 000*	*22.8*	*kg oil-Eq*
Eutrophication: freshwater	*5.78*	*25.6*	*56.5*	*0.043*	*kg P-Eq*
Eutrophication: marine	*0.380*	*1.36*	*4.58*	*0.004*	*kg N-Eq*
Human toxicity: carcinogenic	*18 290*	*57 000*	*16300*	*116*	*kg 1.4-DCB-Eq*
Human toxicity: non-carcinogenic	*33 600*	*164 000*	*148 000*	*111*	*kg 1.4-DCB-Eq*
Ionising radiation	*770*	*2 830*	*33 000*	*2.93*	*kBq Co-60-Eq*
Land use	*154*	*632*	*2 320*	*11.3*	*m^2*a crop-Eq*
Material resources: metals/minerals	*162*	*744*	*1 720*	*37.4*	*kg Cu-Eq*
Ozone depletion	*0.003*	*0.011*	*0.032*	*0.000*	*kg CFC-11-Eq*
Particulate matter formation	*18.2*	*70.6*	*113*	*0.111*	*kg PM2.5-Eq*
Photochemical oxidant formation: human health	*21.5*	*85.2*	*171*	*0.187*	*kg NO_x-Eq*
Photochemical oxidant formation: terrestrial ecosystems	*22.1*	*87.7*	*181*	*0.196*	*kg NO_x-Eq*
Water use	*52.6*	*204*	*859*	*0.559*	*m^3*

Some of the data from the LCA contained data on each subcomponent inside the C1 component as well. This was used in the EIA through gathering data for each subcomponent in a separate document and analyzing which subcomponents had the highest environmental impact. The analysis showed that the subcomponents C1AA, C1AI and C1AJ had the biggest environmental impact and those were more highlighted and discussed in the further work.

The following impact categories where the subcomponents C1AA, C1AI, and C1AJ had the greatest impact were: ecotoxicity (freshwater, marine, and terrestrial), water use, material resources (metals/minerals), and energy resources (non-renewable, fossil). This information was crucial for the "Design for Manufacturing" category in the ECD template, indicating that the manufacturing of these specific subcomponents had a significant impact.
It was important to note that this did not mean the manufacturing phase had the largest overall impact compared to other life cycle phases. According to the LCA report, the most critical phases were the use and maintenance phases. However, even within these phases, the same subcomponents (C1AA, C1AI, and C1AJ) had the greatest impact.

Interviews

Many criteria required information that was absent from the LCA baseline, such as qualitative data regarding materials and end-of-life stages. Various specialists were consulted to support the data gathering, including material, design, environmental, and logistics engineers. While substantial data were compiled for the material category, the end-of-life aspects lacked available information. Furthermore, experts frequently referred the project to other specialists or suppliers for further details, and each interaction yielded valuable outcomes, whether in the form of concrete data or strategic guidance.



🟩 Filled in the ECD template

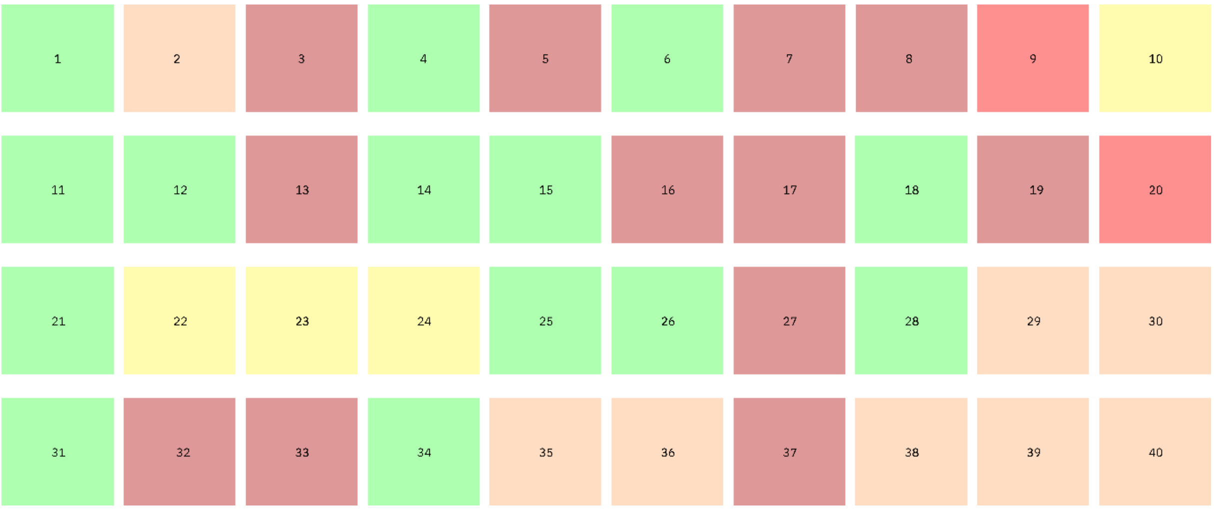
🟨 Approach identified, implementation pending

🟥 Removed (ECD answer: No)

🟧 To be discussed in workshop

🟫 Removed – not reviewed, hidden in ECD

Figure 10: Colour legend to Figure 12



🟩 1	🟧 2	🟫 3	🟩 4	🟫 5	🟩 6	🟫 7	🟫 8	🟥 9	🟨 10
🟩 11	🟩 12	🟫 13	🟩 14	🟩 15	🟫 16	🟫 17	🟩 18	🟫 19	🟥 20
🟩 21	🟨 22	🟨 23	🟨 24	🟩 25	🟩 26	🟫 27	🟩 28	🟧 29	🟧 30
🟩 31	🟫 32	🟫 33	🟩 34	🟧 35	🟧 36	🟫 37	🟧 38	🟧 39	🟧 40

Figure 11: Criteria map

Figure 11 demonstrates the status of each criteria when data gathering was finalised. The coloured boxes show ECD criteria, and the colours represent the data gathering approach. See Figure 10 for the colour legend.

Impact analysis workshop

The workshop successfully yielded a prioritized list of the top ten criteria. However, a significant portion of the session was required to define and clarify these criteria, which subsequently reduced the time available for deeper discussion. The foundational question, "Is it possible and relevant to improve?", often could not be answered with a binary yes or no; instead, it required extensive discussion and occasionally revealed divided opinions within the team. However, the multidisciplinary composition of the group brought highly valuable discussions and perspectives. While some criteria led to repetitive suggestions due to overlapping themes, numerous actionable ideas were generated, primarily focusing on the material phase, transport and packaging, manufacturing assembly, and end-of-life stages.

Visioning (Backcasting)

Envisioning ideal scenarios proved challenging for the participants, who frequently reverted to discussing realistic possibilities and limitations. However, everyone contributed a few thoughts on post-it notes. While it was difficult to continuously integrate this vision into the rest of the workshop due to the lack of a structured framework, regular verbal reminders encouraged ongoing reflection.

The exercise was effective because it established a sustainable mindset and offered a fresh perspective. For example, questions regarding sustainable materials prompted the group to consider alternative material types and processing methods, which became central to further discussions.

Example of the vision-results:

- Increase the recycled materials
- Enable the dissassembly
- Modular products
- Reduce transport
- Zero hazaordus substances

Assessment process

The first phase - material lifecycle phase was discussed extensively, while the final phase (end-of-life) received less attention due to time constraints and lower prioritization. The final phase had limited data, resulting in a brief brainstorming session with few solution suggestions.
Several factors affected the outcome and the quality of the responses obtained: energy levels, time constraints, the amount of data available, the length of each phase, and the team's knowledge.

Survey

The feedback was largely positive, with most respondents finding it positive for broadening perspectives and creative thinking. Some felt constrained by the need to focus on finding solutions. One of the biggest challenges included understanding certain ECD criteria and knowledge gaps in the environmental impact.

The backcasting part at the beginning helped most participants to broaden their perspective and see long-term solutions, although some felt limited in their thinking. The biggest challenge with the ECD criteria and backcasting method was understanding and contextualizing certain questions and metrics. Some questions were perceived as unclear and similar, making prioritization difficult. The likelihood of using the method again varied between 2 and 4 on a scale from 1 to 5. Open discussions and the mix of competencies were considered most valuable for identifying improvements.

Some aspects of the ECD methodology were found to be confusing, particularly regarding the similarity of certain questions. Most participants believed the method could lead to actual improvements for Saab, provided the construction department receives suggestions with an open mind and there are economic incentives. Participants expressed a desire for a more integrated environmental approach in Saab's regular work and appreciated the well-planned and executed effort. There was also a call for a more direct approach to environmental work and for Saab to market itself as eco-friendly by integrating environmental considerations into everyday operations.

Results

The analysis and discussions from the workshop gave many potential suggestions and ideas, as well as the insight into the potential of improving each criteria. The top 10 criteria included the material phase, manufacturing, packaging & transport and end-of- life (see Table 4). These descriptions do not constitute the assessment criteria; rather, they indicate the areas on which the criteria focus.

Table 4: ECD result - top 10 criteria

2. Reuse of products
29. Ease of maintenance
30. Design for reparability
35. Recycle components, e.g. by design for disassembly
10. Low environmental footprint materials
18. Packaged product size and weight
24. Recycled materials in packaging
6. Hazardous substances
15. Emissions during manufacturing
21. Reuse of packaging

The discussions confirmed that the subcomponents C1AA, C1AI, and C1AJ were the most challenging ones, due to their complexity. Maintenance was mentioned numerous times as an important aspect and problem. The same applied to assembly. Disassembly part of the manufacturing was an area that was repeatedly mentioned. The criteria that received the highest scores were heavily focused on reuse, maintenance, and design for disassembly. These were interesting areas to explore. However, it should be noted that there was no gathered data available on these topics.

KJ analysis

During the KJ analysis, the workshop citations were organized into five lifecycle phases. Within each phase, the citations were grouped by the different topics they addressed. For example, the lifecycle phase "Design for material sourcing" contained several topics that were discussed such as: material suggestions, laws, components, production, specific material. Analyzing the KJ structure, it could be noted that the discussions were bigger regarding the material phase than the others. There can be several reasons for that, the participants were more engaged in the beginning of the workshop and had more energy and therefore, the material phase got more time since it was the first one. Moreover, there were several material experts in the workshop team.

Analysis of the results

The result was based on the calculations the ECD Assessment Template made in the end of the workshop. Those were based on the area criteria covered (environment, climate, circularity), whether the criteria had the needed data or not and whether working on them is mandated by law. These calculations led to different scores. The highest ones in the top 10 list were prioritized because of the unavailable/absent data, meaning that those criteria have higher potential for improvement since there was a lot more unknown aspects to investigate. Since those were considered as higher improvement potential – it became clear that those needed to be more highlighted and worked with. These 10 criterias could be categorized into three main areas: material, packaging and maintenance & assembly.

At the workshop, it was estimated that the component C1AI is a subcomponent that cannot easily be changed due to its complexity and sensitivity. Therefore, further focus was put on C1AA and C1AJ. Although C1AJ was not included in the results of the Life Cycle Assessment (LCA) in the report, data from the "Design for manufacturing" phase and discussions during the workshop confirmed its significant impact on the component based on several criteria. The workshop confirmed that the subcomponents C1AA, C1AJ, and C1AI were the most complex, which explains why they had the highest environmental impact in the Manufacturing phase. This information was valuable for further improvement planning and the concept development phase.

Evaluation of the workshop

As the time constraint was affecting Part 2 – Improvement planning of the workshop, the improvement planning was not as detailed as needed. The participants discussed some of the suggestions for the actions during the whole workshop, but there was no structured improvement planning for the results of the top 10. Focus was on the understanding and the discussion of the criteria.

Conducting workshops in domains where adequate expertise was lacking, such as environmental aspects, presented a significant challenge. Additionally, synthesizing conclusions within a constrained timeframe and providing an answer with YES or NO to the question of whether there is potential for improvement or not was challenging. This was partly because of the short time frame, but also because the answer was not always simple. Additionally, participants had different opinions (environmental vs. design), making it difficult to weigh them. Sometimes the answer might lean towards NO because it was difficult to achieve a change in the relevant criteria, but there were still certain ways and smaller things to look at that would contribute to a greater reduction in environmental impact in the long run.

3.2.2 Part 2 – Improvement planning

Defining actions and scoping

The brainstorming and research sessions were short and needed to be further explored. However, the outcome within the given time frame was used later in the follow-up interviews. The research gave some insights into how other institutions take on the same questions, for example, RISE. Material replacements were researched, for example, several types of bioplastic materials. The process involved reviewing each criterion and the corresponding actions from the workshop to generate further ideas, which consisted of either expanding on existing workshop suggestions or introducing new concepts.

Several criteria were evaluated and some were excluded or combined to streamline the improvement process. Criteria aiming to explore issues in the assembly phase were merged to concentrate on the more manageable aspects of assembly. Multiple criteria addressing packaging materials were merged and the related design suggestions were transferred to broader criteria for transport and distribution. These changes ensure a more efficient and effective improvement process by focusing on the most actionable and impactful areas. A copy of the ECD template was made with the remaining 6 criteria. The new list also included new columns: Suggestions from the workshop, researched actions, brainstormed actions and vision. The remaining six criteria could be grouped into the 3 main areas with 2 criteria each (see Table 5).

Table 5: Example of actions

Area	Criteria	Action-example
1. Material	5. Low environmental footprint materials	Increase recycled aluminum
	8. Hazardous substances	Reduce cadmium

2. Packaging	10. reuse of packaging	Analyze transport damages
	6. Product packaging size and weight	Redesign the packaging
3. Maintenance& assembly	2. Ease of maintenance	Increase modularity
	4. Recycle components, e.g. by design for disassembly	Design for assembly/dissasembly

Category 3 – Maintenance & assembly combined improving the product's maintainability, assembly efficiency, and end-of-life management. The criteria emphasized ease of maintenance, increased modularity, and design for assembly and disassembly to simplify production, servicing, repair, and component separation. These aspects were combined due to similar improvement suggestions discussed at the workshop.

Follow up interviews

The criteria discussed in the material – interview:

- Low environmental footprint materials
- Hazardous substances

New ideas and a better overview of opportunities in these three areas and how they interconnected were explored. The most hazardous substances in the material sector were discussed, specifically lead and cadmium. Lead-free solders were highlighted as a potential area for improvement. Additionally, reducing the use of adhesives was emphasized as a crucial aspect of moving towards greater sustainability. Material requirements were also discussed, with one of the proposed solutions being the increased use of recycled materials.

The criteria discussed in the assembly – interview:

- Ease of maintenance
- Recycle components, e.g. by design for disassembly

The backcasting aspect was included with a question "What is a dream scenario for the assembly process?". The answer from the interviewee was "For the assembling process to be faster, to skip the glueing part." The two subcomponents that had the highest impact and were most complex were brought up: C1AA and C1AJ. The third one was not mentioned at first but came up later: C1AI (due to sensitivity for changes). The potential problem was revealed as a "low-hanging fruit". The process of assembling part C1AI was time-consuming, ergonomically unsustainable, and brought quality risks. The crucial issue was the gluing process. In response to the question of what vision was desirable for this process, the answer was that the most ideal scenario would be to have no gluing process.

Improvement suggestions for the three main areas

The key suggestions from the workshop and the follow-up meetings were:

1. Material
    a. Hazardous substances: Address the use of lead and cadmium by exploring lead-free soldering and other solutions.
    b. Adhesives: Reduce the use of adhesives to enhance sustainability.
    c. Recycled materials: Increase the use of recycled materials to meet high-performance requirements.
2. Packaging
    a. Recyclable materials.
    b. Analyze the damage during the transport.
3. Maintenance / assembly

a. Effectivity: Aim for a faster assembly process that eliminates the need for gluing.
b. Ergonomics and quality: Address the time-consuming, ergonomically unsustainable, and quality-risk process of assembling part C1AI

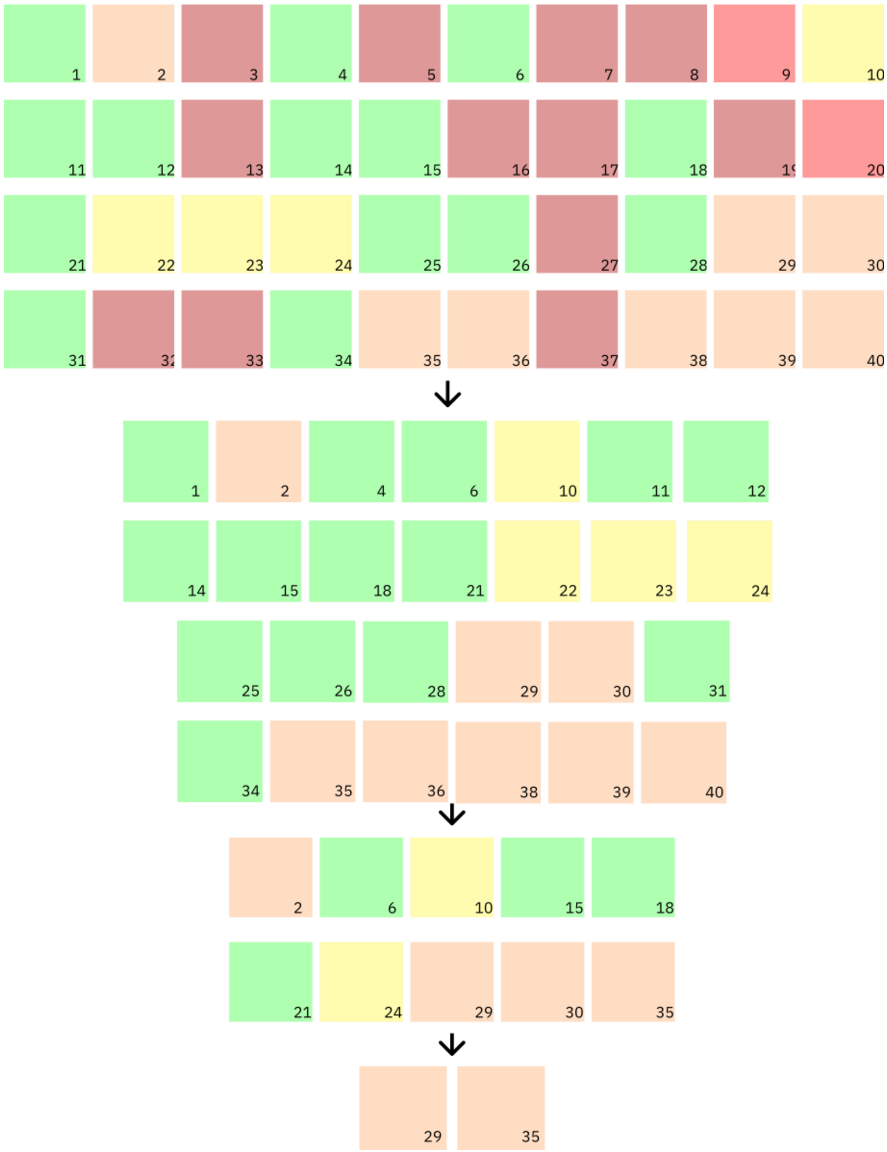


Figure 12: Development process of scoping the criteria

3.3 Phase 3 – Concept development

The activities and outcomes from the concept development phase are demonstrated in Figure 16.

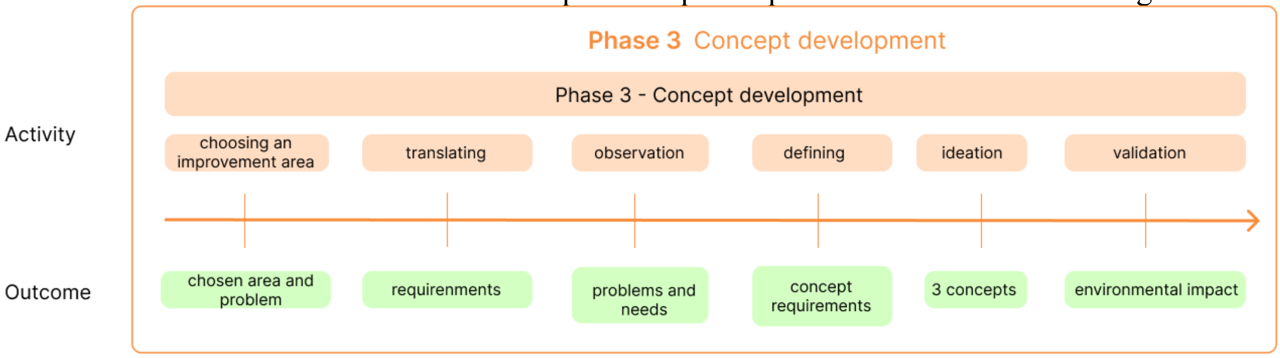


Figure 13: Timeline of activities and outcomes of Phase 3 - Concept development

3.3.1 Problem definition and scoping

Choosing an improvement area

In the concept development phase, it was crucial to select a specific area to focus on, based on the results from Phase 2 – ECD application (see Figure 12). An area was chosen from Category 3 – Maintenance & assembly in Phase 2, Part 2 – Improvement planning. The chosen area of improvement was the assembly part of the production, specifically the assembly of the subcomponent C1AI. See Figure 14 which illustrates the decision process.

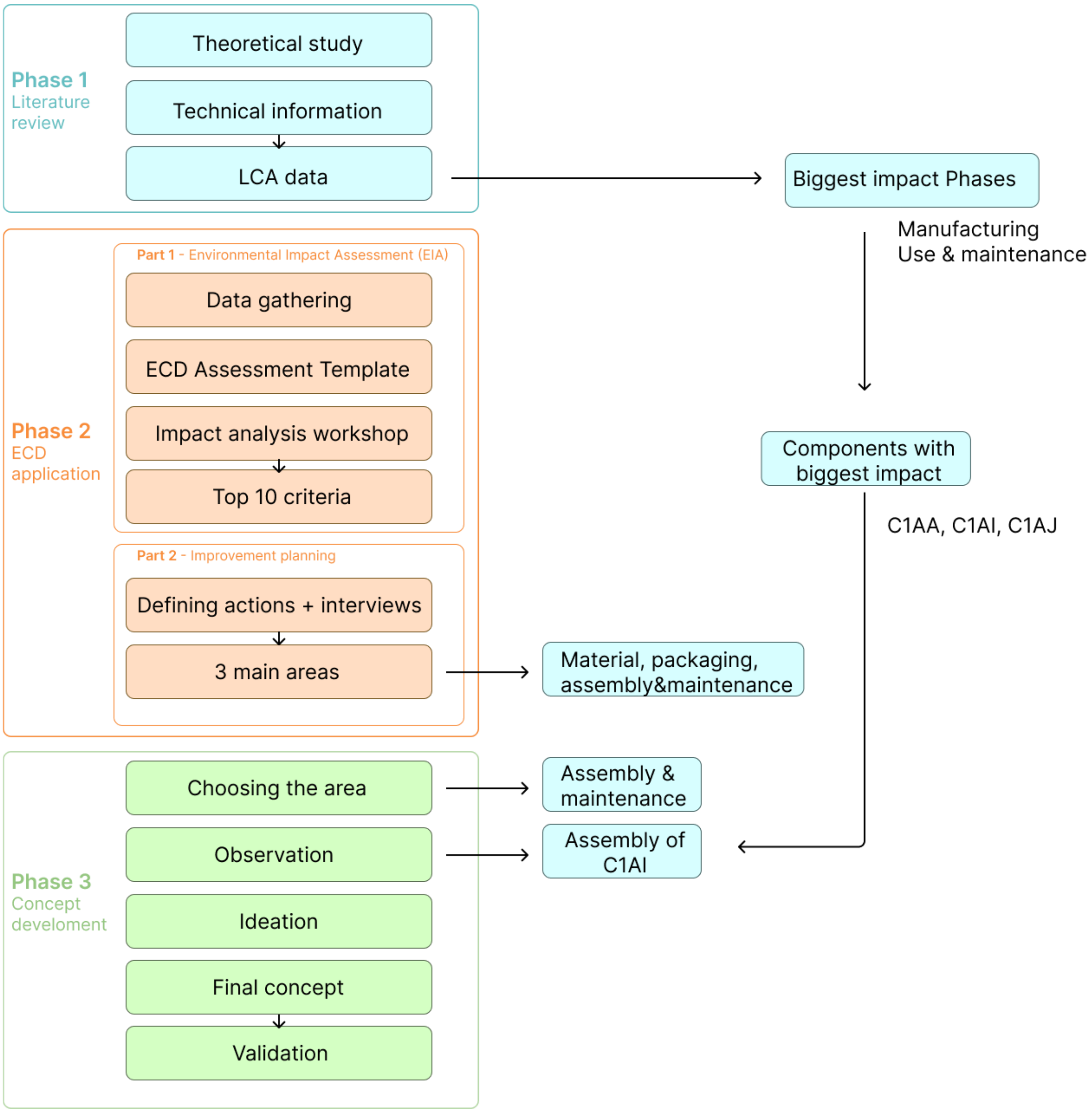


Figure 14: Connection between the LCA data and the chosen C1AI component

Assembly was particularly interesting because it impacted both maintenance and a significant portion of the end-of-life phase, which Saab has not extensively explored. This lack of focus meant that there was limited data available, making it both challenging and interesting. The absence of data provided the freedom to innovate and explore new approaches, such as sending products back to Saab for recycling or designing for disassembly. Additionally, assembly and disassembly were frequently mentioned in workshops as areas with substantial potential for improvement. Even if component C1AI was not part of the results of the LCA report, big part of the data showed that C1AI had a large environmental impact and therefore it was chosen to be explored and developed. Choosing to improve the assembly of subcomponent C1AI offers an opportunity to address multiple environmental challenges, from maintenance and end-of-life management to resource efficiency and innovation in recycling.

Translating actions into requirements

Actions:

Explore current gaps in the assembly phase.

- Examine the C1AI and its current adhesive application:
  - Look at the C1AI and how it is glued – find an alternative solution.
- Design for assembly/disassembly:
  - Identify which parts of the process take the most time.
  - Examine the most complex subcomponents.
  - Consider modular design to reduce adhesive use where possible – making it easier to assemble and disassemble.

Requirements:

The vision: *mount the C1AI without adhesive.*

- Reduce time in the most time-consuming part of the process.
- Assemble the C1AI in a different way.
- Implement a modulardesign.
- Reduce adhesive use.
- Facilitate assembly.
- Create a more circular system after end-of-life.
- Facilitate disassembly.

3.3.2 Observation

The observation of the gluing process for C1AI provided valuable insights into the current operational challenges and areas for improvement. Several visits were made, yielding new input and generating new ideas. It is important to note that the visits and ideation phases were iterative.

The observed process involved an manufacturing operator working in the production area, gluing components onto the C1AI as part of their regular duties. The process was detailed and consisted of 14 steps, including preparation, adhesive application, and curing. The gluing process included gluing of 12 holders and a component called ferrites which can be seen in the Figure 15. The main observed components being glued were the holders, which served the purpose of securing screws for other components that attach to the C1AI.

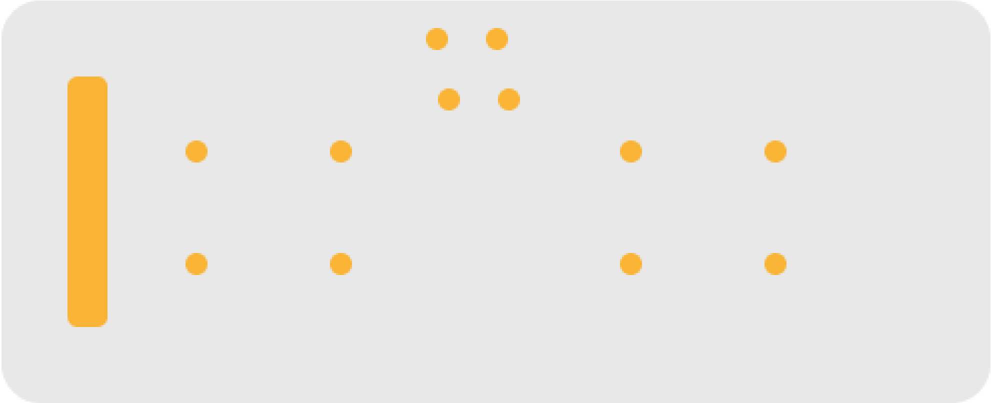


Figure 15: The glued components onto C1AI, "ferrites" is the rectangular shape and the 12 circles are the holders

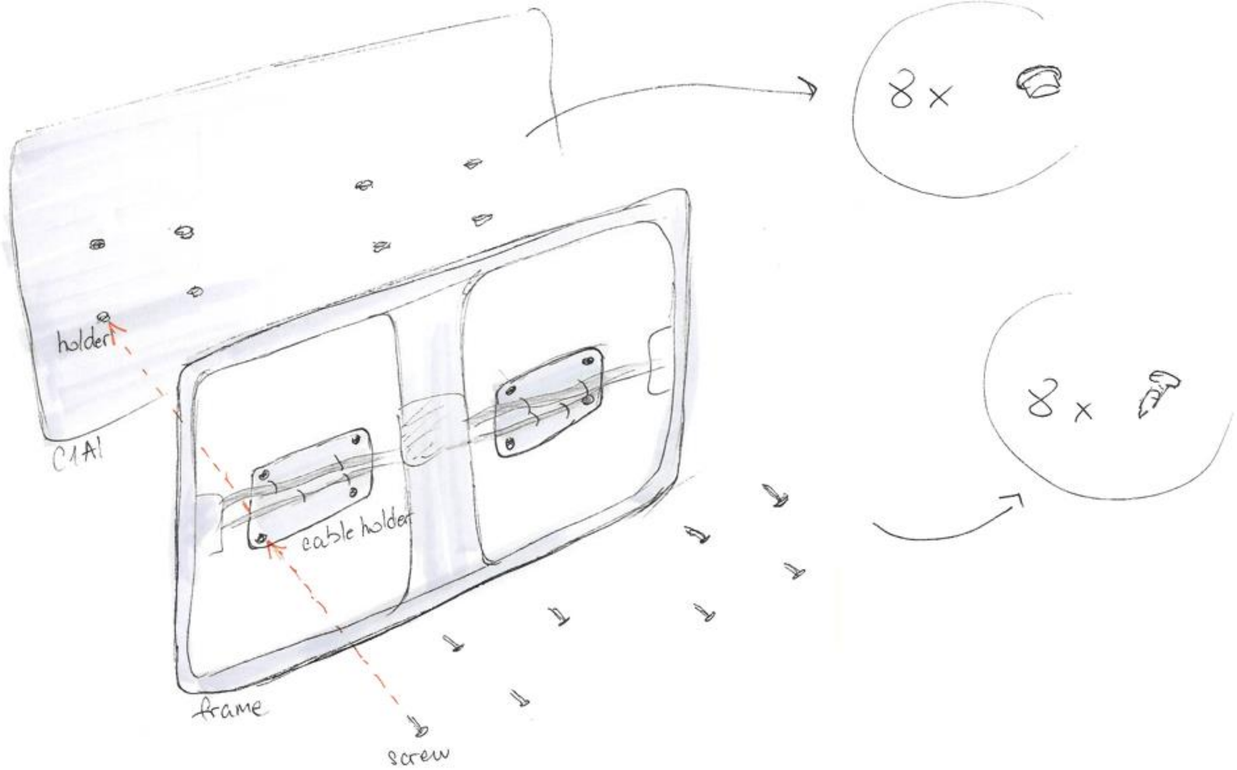


Figure 16: Assembling C1AI with the frame&cable holder

Figure 16 illustrates the assembly process that typically took place after the cable holders have been glued into position. The C1AI was attached to the frame, and eight screws were used to fasten the cable holders to the eight corresponding holders located on the C1AI.

Some health concerns centered around exposure to hazardous substances present in the adhesive, which are associated with the following health hazard statements:

- H315 – Skin irritation
- H217 – Allergic skin reaction

The observations provided a comprehensive understanding of the current gluing process and the associated challenges. The defined problems and issues served as a foundation for developing solutions that improve efficiency, reduce stress, ensure quality, and address health concerns.

Observed problems during the gluing process

1. Health concerns:

    - Risk of inhaling hazardous substances and allergic reactions during the adhesive application process.

    - Need to work in a controlled environment (fume hood) to minimize exposure to fumes.
    - Frequent changing of gloves due to adhesive seepage, which can lead to skin irritation.

2. Glue application challenges:
    - Difficulty in ensuring no air bubbles are present in the adhesive.
    - Complex and time-consuming process of applying adhesive.
    - Challenges in filling the adhesive applicator and ensuring proper mixing.
    - Issues with the adhesive applicator creating a vacuum, preventing adhesive from being dispensed.
3. Ergonomic issues:
    - Working with a mirror and adhesive around the plate is physically demanding.
    - Uncomfortable positions and angles, especially for inner holders.
    - Need to rotate the C1AI frequently to access all holders.
4. Mental stress:
    - Mental strain from uncertainty about the quality of adhesion.
    - High level of focus required to ensure proper adhesive application.
    - Complexity and precision required in the process.
5. Quality concerns:
    - High cost associated with the C1AI if errors occur.
    - Difficulty in re-bonding the components if initial adhesion is faulty.
    - Ensuring the adhesive holds properly and does not fail under stress.
    - Sensitivity of the C1AI to impacts and careful handling required.
6. Time-consuming process:
    - The adhesive process is time-consuming, taking at least an hour for experienced workers and up to two hours for less experienced workers.
    - Long cure time of 24 hours, during which the C1AI cannot be moved.
    - Inefficient use of space and time due to the curing process.
7. Material and equipment issues:
    - Gloves need to be changed frequently as adhesive seeps through after 10 minutes.
    - Challenges in handling and applying the adhesive due to its viscosity and curing properties.

The meetings with an assembler and technicians provided valuable insights into the G1X structure, which featured a frame where the C1AI was later mounted (see Figure 17). The components requiring holders currently glued onto the C1AI, as well as two cable holders that were screwed onto it were demonstrated. Observing the frame and assembly system revealed that the cables fastened to these holders were not dependent on the C1AI. This gave the conclusion that the cable holders could be fastened in another way, reducing the need for glued holders on the C1AI. That idea was discussed with technicians, who provided a technical perspective on the feasibility and impact of this alternative method, concluding that cable holders could be integrated into the frame. As shown in Figure 17, the cable holder was temporarily attached to a rectangular object to hold it in place before it was attached to C1AI.

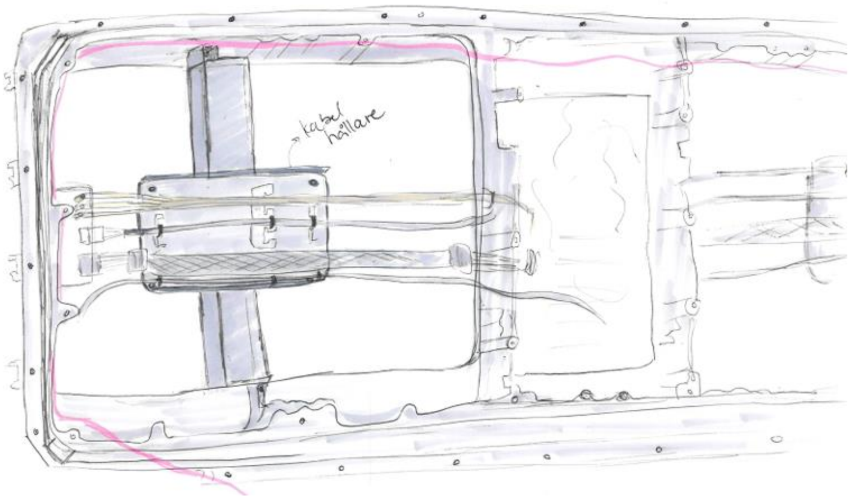


Figure 17: The existing frame and cable holder

These insights helped develop solutions to improve efficiency, reduce complexity, and enhance the overall quality of the assembly process. The idea of fastening cable holders to the frame showed promise for further exploration.

3.3.3 Defining requirements

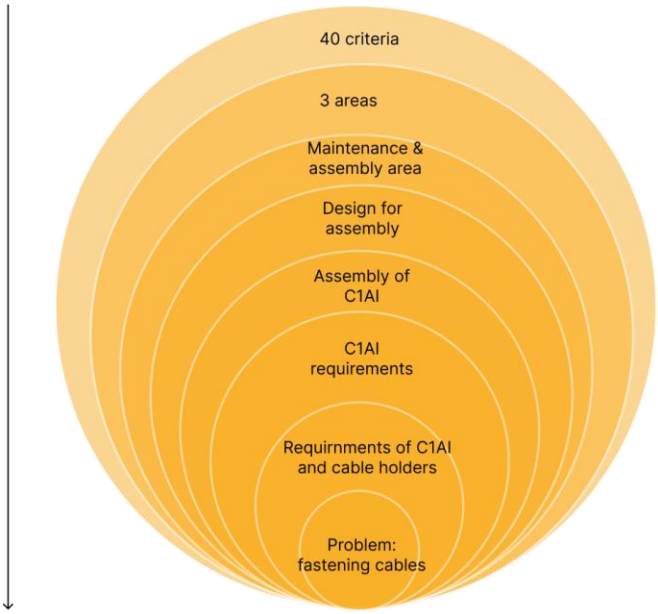


Figure 18: Defining the problem

Figure 18 illustrates the process of identifying the underlying problem in the previous steps. The process began with the 40 criteria provided in the ECD template and gradually narrowed down to the selected focus area – the maintenance and assembly area. From there, the specific component being assembled, C1AI, was identified, followed by an exploration of its requirements and those of related components. This systematic analysis ultimately led to the identification of the root problem: cable fastening.

Problem and user needs

The adhesive application process encountered several challenges. Health risks, particularly from hazardous substances, were significant; the process was complex and time-consuming, leading to ergonomic issues and physical strain and quality concerns were high due to the cost of errors. Quality depended heavily on individual focus and skill. Time and space were used inefficiently, and consistent adhesive application proved challenging. Based on these problems, user needs were defined below.

Needs:

- Simplify and streamline the adhesive application process.
- Improve ergonomics and reduce physical strain.
- Reduce mental stress through clearer guidelines and better tools.
- Ensure high-quality adhesion and minimize errors.
- Optimize the use of time and space in the process.
- Address material and equipment issues to improve handling and application of adhesive.
- Explore alternative methods for securing components without adhesion.

Product requirements (C1AI)

General technical requirements to consider in the concept while designing:

- Weight management: Avoid adding too much weight to the concept
- No drilling: Drilling into the C1AI is not permitted
- No welding: Adding material to the C1AI through welding is not allowed
- Modifications to cable holders: Cable holders can be drilled, modified in shape, and otherwise altered as needed

Design concept requirements

The specific part to re-design was the cable holder (see Figure 19). The requirements and specification list for that process are listed in Table 6.

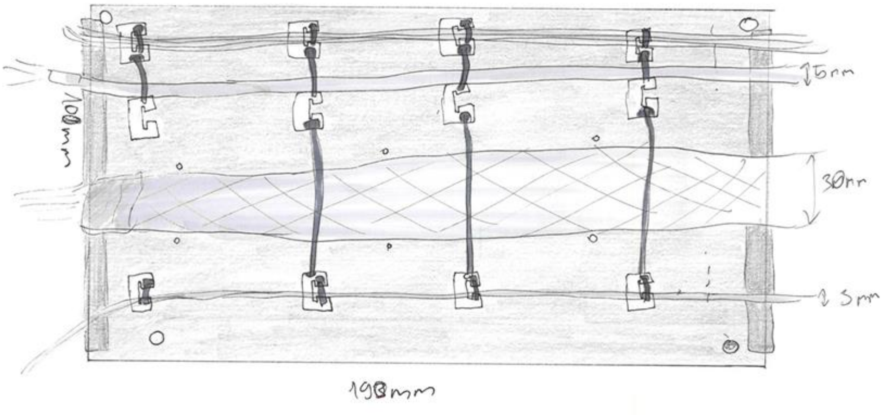


Figure 19: The existing cable holder with cables

The main function that needed to be addressed was that the cables move around and need to be held stable.

Aim: Find alternative methods for securing cables without the need to attach anything to the C1AI.

Objective: Eliminate the gluing process from the C1AI by finding other ways to secure the cables.

Problem question: In what ways can the cables be held in place?

Table 6: Requirements and Specification list

Requirements
The cables need to be held securely in place.
They should not be attached to, screwed into, or come into contact with C1AI.
The cables are not allowed to change their position
Specification list
Securely hold the cables in place.
Attach the cables in a way that does not contact the C1AI.
Ensure that the cables can be connected correctly and in the right position.
Facilitate easy cable assembly without adding extra steps.
The solution for holding the cables should be integrated into the frame.
Design for disassembly (consider this during the design phase).

3.3.4 Ideation

Ideations 1 and 2 began after conducting observations and meetings. The primary consideration was that the solution would be integrated into the frame, with cables fastened directly to it. Various shapes and designs were explored to achieve this integration. See Figure 20.

Ideation 2 resulted in multiple methods for holding the cables, moving beyond simple plates and plastic bands. This session produced diverse perspectives, including objects with grooves to fit the cables and plates assembled to create a "bag" for cable organization.

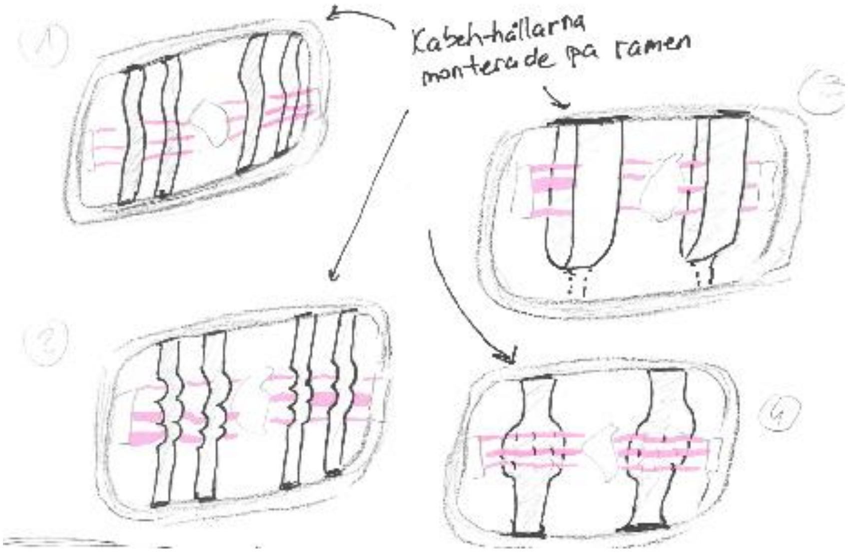


Figure 20: Ideation 2

A final brainstorming and braindrawing session were conducted before selecting the final concept. The Ideation 3 phase yielded three concepts, which were evaluated and compared to determine the most suitable solution.

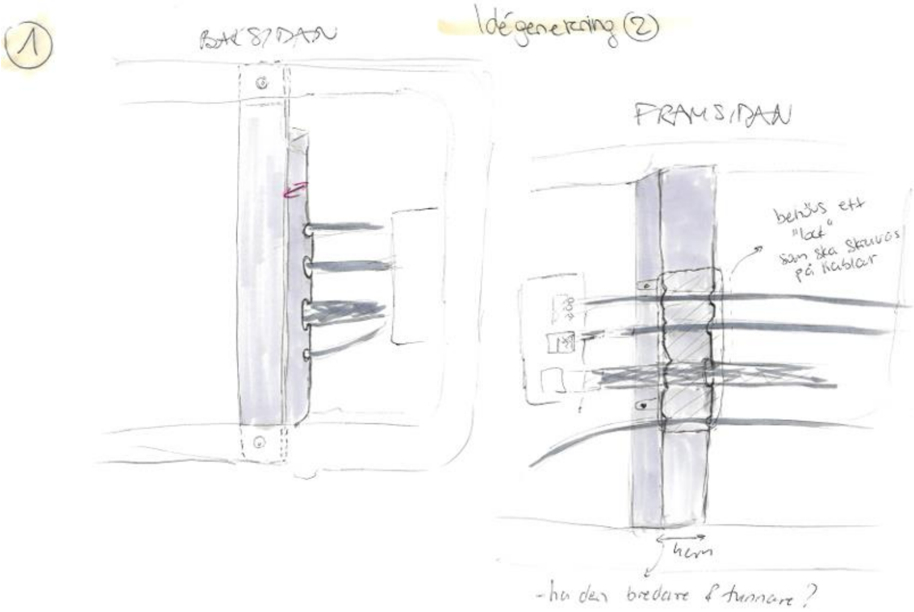


Figure 21: Concept 1

Concept 1 presents a solution featuring a cable holder that is seamlessly integrated into the frame. This shape was inspired by the temporary object that held the cable holder in place (Figure 17). The surface of the material includes small, precise channels designed to hold cables. To ensure cable security, a removable lid covers these channels, protecting the cables from damage, retaining them in place, and providing a finished, aesthetic appearance. This lid is easily accessible for maintenance or modifications, making the design both practical and user-friendly (see Figure 21 and Appendix D).

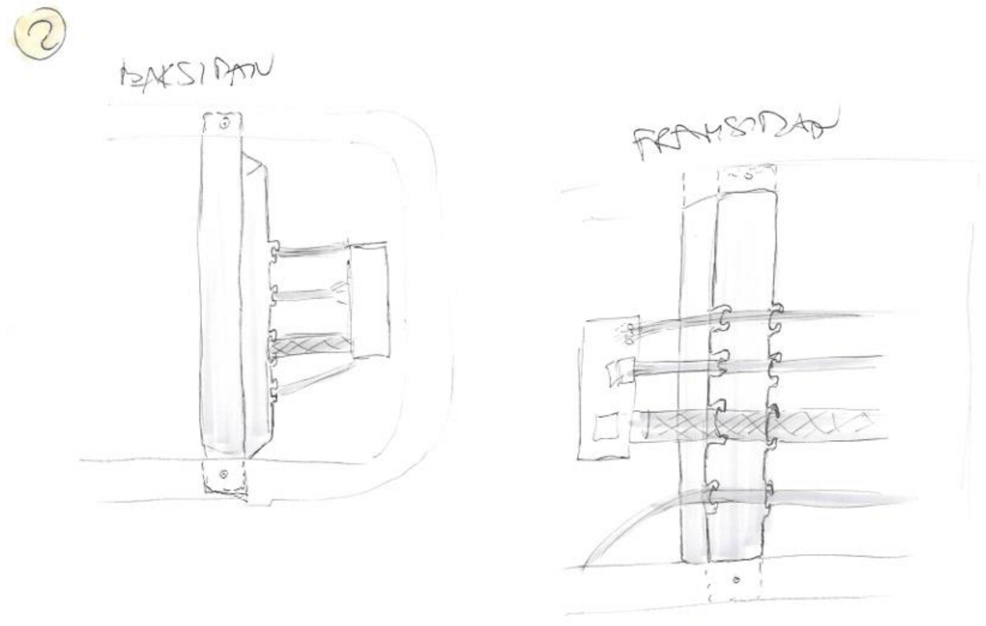


Figure 22: Concept 2

Concept 2 offers a solution similar to Concept 1, featuring an integrated cable holder within the frame. However, instead of using a lid to secure the cables, this concept employs small clamps to fasten the cables in place. Various clamp designs were developed and explored to ensure optimal performance. This approach provides flexibility in cable management while maintaining a streamlined and integrated design (see Figure 22).

After the meetings with the technicians, some of the concept ideas were ruled out based on feasibility concerns. For example, the cable holder with clamps that required bending cables was immediately excluded, since the cables would probably get damaged by bending to fit into the clamps.

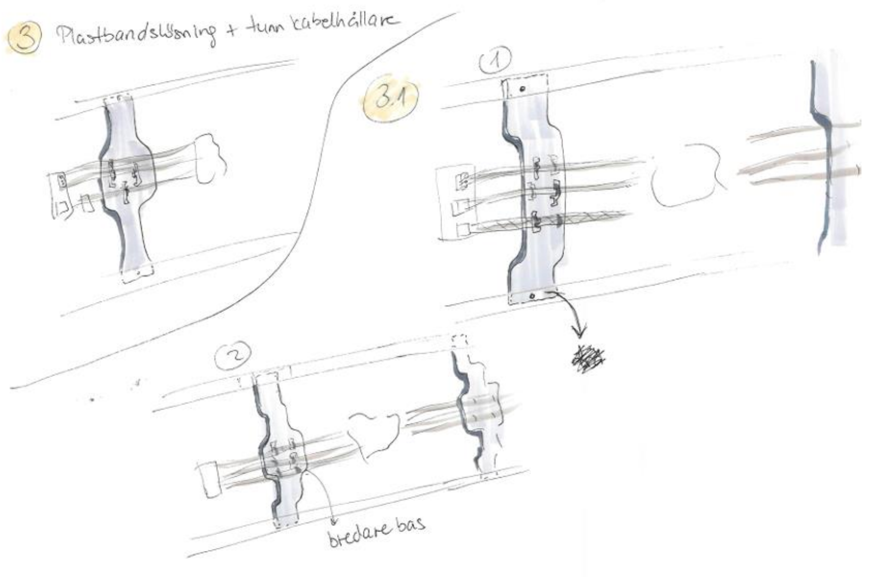


Figure 23: Concept 3

Concept 3 revisits the existing cable holder design, which secures cables using plastic bands. Similar to the previous concepts, this cable holder would be integrated into the frame. However, this concept had the thinner structure and used less material. Various geometric designs were explored to optimize the integration and functionality of the cable holder within the frame, ensuring a seamless and efficient solution (see Figure 23).

3.3.5 Final concept

Concept evaluation (choosing concept)

Final meetings with experts were conducted to refine and finalize the concept. Key steps included making final changes to the concept, visualizing the final concept through sketches, and gathering feedback from various engineers and designers. The CAD engineer confirmed the feasibility of producing the component as proposed. Concept 3 was chosen for its potential, although other concepts were also noted for their advantages. The engineer's feedback was crucial in determining which concept to refine further. The engineer concluded that the cable holder's design could be manufactured and integrated with the frame through milling. This method was chosen because milling is the currently used process for manufacturing the frame, ensuring efficiency in production. Development of the final concept - sketching continued to develop the final concept, based on concept 3. A general engineer, design manager and design engineer of C1AI approved the concept ideas, confirmed their viability and discussed the implementation potential. Additional ideas were generated, such as finding similar solutions for other holders glued onto the C1AI to further eliminate the need for gluing.

Visualisation of the final concept

The additional component information was gathered successfully. The final concept consists of an integrated cable holder machined directly into the frame, replacing the existing separate cable holders that are bonded to the C1AI with adhesive (see Figure 24). The design follows the principle of the current cable holder by using plastic bands to secure the cables, ensuring that cable routing and positioning remain unchanged while eliminating the need for gluing. The integrated geometry allows the holder to be manufactured as part of the existing frame using the current milling process, making the concept feasible without introducing additional manufacturing methods.

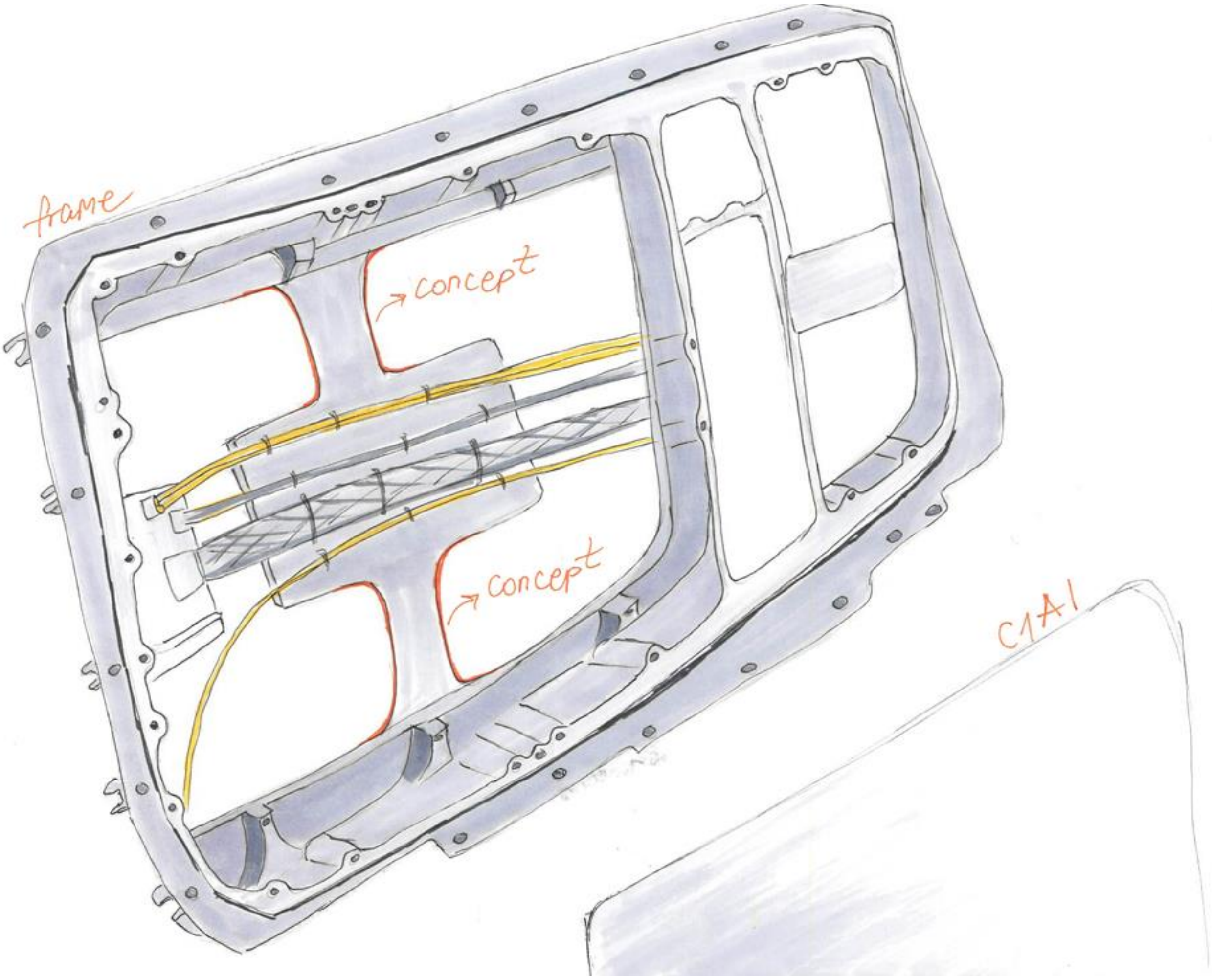


Figure 24: The final concept

The final concept consists of two integrated cable holders, each attached to the frame at both ends. Consequently, the design adds four integrated aluminum sections to the frame (see Figure 25). Each section has approximate dimensions of 50 × 145 × 2.5 mm, corresponding to a volume of 18,125 mm³. Assuming an average aluminum density of 2.7 g/cm³, the estimated mass is 48.9 g per section, giving a total added mass of approximately 195.8 g for all four sections.

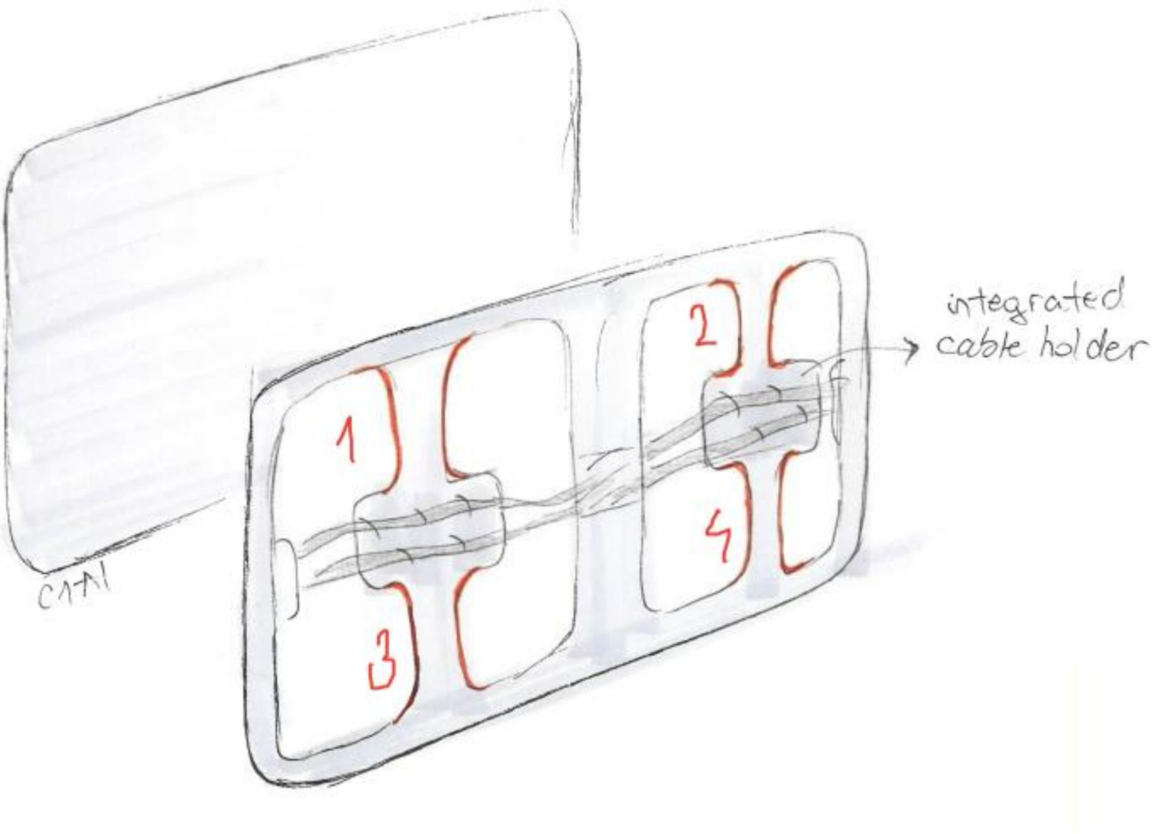


Figure 25: The final concept

The given measurements were suggested for the added material to the final concept:

- Volume: V = 50 x 145 x 2.5 = 18. 1 mm³
- Mass: Using an average density of aluminum (2.7 g/cm³), the mass for four pieces was 195. 8g (See Figure 29)

Additionally, this type of solution can have two different scenarios. In Scenario 1, the proposals would change the design of the two cable holders, with the final concept presented above which results in reducing the gluing process of eight holders onto the C1AI (see Figure 26).

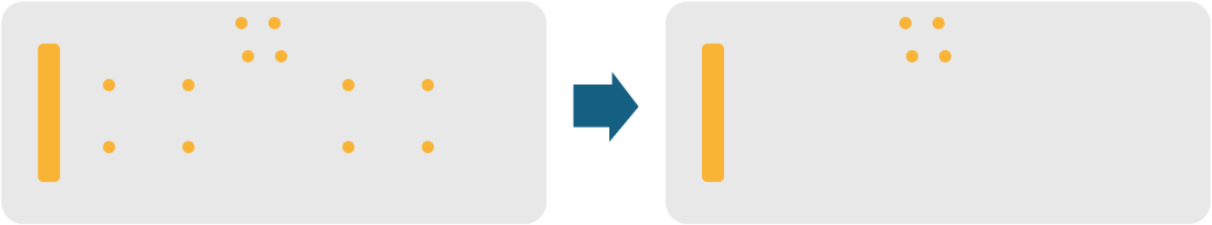


Figure 26: Solution scenario 1, before & after

With this solution, the number of holders requiring gluing could be reduced by eight, leaving only four holders and the ferrites that need gluing, as illustrated in the right rectangle.

In Scenario 2 (see Figure 27), a broader solution was proposed based on discussions with technicians and engineers. This solution involved moving the gluing of ferrites to the supplier. Additionally, it was suggested that the remaining four holders could either be soldered or glued by the supplier, or similar alternative solutions could be explored to eliminate the need for in-house gluing. These changes would then lead to a total replacement of the gluing process with another solution. The remaining gluing component, the ferrites, would be moved to the supplier, eliminating the gluing process from Saab's facilities. However, even this part needs to be reviewed to explore potential solutions for replacing the gluing process. It is important to note that Saab's guidelines aim to exclude such processes both internally and externally with suppliers. Therefore, efforts will continue to identify alternatives to gluing, even if the process is transferred to the supplier, to align with Saab's commitment to process improvement and sustainability.

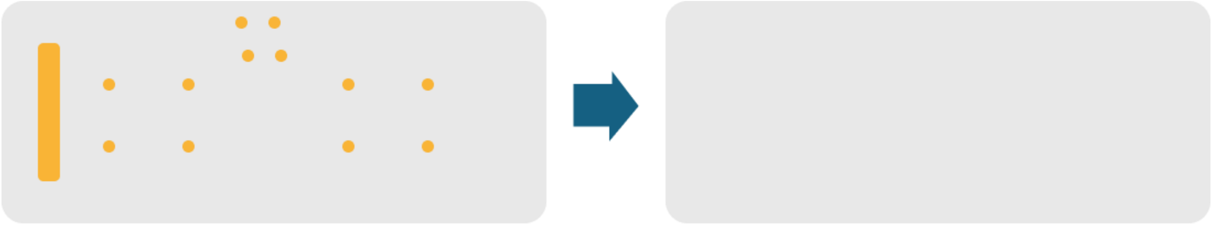


Figure 27: Solution scenario 2, before & after

3.3.6 ECD criteria mapping

The proposed solution of milling the cable holders as part of the frame aligns well with several key criteria of the ECD methodology that were chosen to work with.

Manufacturing criteria

The assembling part of manufacturing is streamlined and made more efficient. In Scenario 1, the gluing process is reduced, which minimizes the time and labor required for this step. This reduction not only speeds up the assembly line but also decreases the associated costs. In Scenario 2, the gluing process is entirely excluded, further enhancing efficiency. By eliminating the need for gluing at Saab, the assembly process becomes faster and more reliable, as it reduces the potential for errors and inconsistencies associated with adhesive application.

By integrating the cable holders into the frame through milling, the amount of aluminum waste generated during the milling process is reduced. Since the frame is already milled from a large aluminum plate, this approach allows for more efficient use of the material. As a result, a greater portion of the aluminum is retained, and less is discarded. Although some of the material waste may be recycled, it is still more advantageous to use the material directly. This contributes to more sustainable manufacturing practices and efficient use of material.

Material criteria

Even the criteria from the material category were positively impacted. The design aims to minimize the use of hazardous substances. By reducing the need for separate cable holders that may require additional adhesives or fasteners, the overall exposure to potentially harmful materials is decreased. This aligns with the goal of creating a safer and more environmentally friendly product.

Adhesives contain substances that can negatively impact human health and the environment. By minimizing or eliminating the use of adhesives, the overall environmental footprint of the manufacturing process is reduced. This leads to a more sustainable and eco-friendly production method. The solution emphasizes the use of low-footprint materials. By optimizing the milling process to integrate cable holders into the existing frame, the design makes efficient use of aluminum, a material with a relatively low environmental impact compared to other options. This approach supports the objective of reducing the overall environmental footprint of the product.

Synthesizing these specific ECD criteria into a broader lifecycle perspective, the baseline LCA data showed that the use & maintenance phase dominates the environmental impact, use stage remains unchanged since the radar's operational performance is unaffected. However, maintenance is enhanced due to efficient assembly. Additionally, the new design creates significant benefits in the material and manufacturing phases by streamlining and simplifying the assembly process while minimizing the use of hazardous substances. Furthermore, transportation is improved as eliminating separate parts results in fewer, more compact components to pack. Finally, the end-of-life phase is slightly improved, as the simplified structure allows components to be more easily separated for recycling.

3.3.7 Concept validation

The validation process involved an analysis of the environmental impact associated with both the current design and the proposed design concept. The findings are summarized below.

During the validation process, the following steps were undertaken:

- The weight of the current and redesigned components was calculated.
- The material costs were assessed.
- CO2 emissions were evaluated.

The CO2 emissions did not show a significant difference, depending on the measurements of the design and the added weight which could be around 200g based on the suggested measurements. However, the material cost became considerably lower, due to reducing the number of components. It is important to note that the current sub-components include manufacturing costs in their price, so the costs cannot be defined with certainty. Overall, the redesigned component results in cost reductions due to decreased adhesive application time and labor hours.

Social sustainability

Worker safety: The design proposal reduces exposure to hazardous substances, improving worker safety, and mental well-being.
Ergonomics: The new design enhances ergonomics by reducing repetitive and strenuous tasks, such as gluing and drilling, leading to better working conditions and reduced stress.
Overall well-being: The improvements in ergonomics and reduced exposure to hazardous substances contribute to the overall mental and physical well-being of workers.

Material environmental Impact

Adhesive: The carbon footprint of the adhesive was relatively small for the given quantity but accumulated overtime due to frequent use of adhesive. Reducing the gluing process can enhance environmental sustainability by minimizing exposure to hazardous substances.
Material weight and emissions: The carbon dioxide emissions associated with the materials varied depending on the measurements and material weight of the final concept. The difference in emissions between the current solution and the design proposal was minimal.
Manufacturing process: The impact of the manufacturing process was significant. It involved extensive gluing, exposing workers to hazardous substances for many hours. The milling process extracted more aluminum than it would with the final concept. The design proposal eliminated these steps, improving overall environmental and social sustainability.

Costs

Production efficiency: The design proposal improved production efficiency by reducing steps such as gluing, drilling holes for screws, and manufacturing cable holders. This reduces assembly time, enabling mounting several C1AI in a shorter timeline. This leads to faster production cycles and more efficient processes.

Product performance and quality

Structural integrity: The design proposal enhances the frame's structural integrity and robustness by integrating cable holders directly into the frame, thereby adding significant value to the overall structure and reduces the need for frequent repairs or replacements of the glued holders.

Reduced risks: Quality and process risks are significantly reduced, particularly the risk of adhesive failure, which would require re-gluing and repeating the entire process for the C1AI component. This results in a more reliable product.

Analysis

The cost implications need further calculation, particularly considering the reduction in gluing hours and the associated labor costs. However, the milling process for the frame involves several steps that must also be accounted for. Depending on the measurements and subsequent material weight of the new solution, the carbon dioxide emissions will vary. The difference in emissions between the current solution and the design proposal is minimal. Nevertheless, the environmental impact of manufacturing is more critical in this context.

While the exact environmental impact was too complex to fully quantify in this project (material impact was calculated, but manufacturing was complex), several conclusions can be drawn. The current solution requires extensive gluing and curing hours, exposing workers to hazardous substances. In contrast, the design proposal eliminates these steps, including gluing, drilling holes for screw-mounted cable holders, manufacturing eight separate holders, and producing cable holders. By integrating cable holders into the frame through milling, aluminum waste is reduced. This approach also enhances social sustainability by minimizing exposure to dangerous substances, improving ergonomics, and reducing mental

With Scenario 1, the final concept reduces gluing time and eliminates the need for eight separate holders, thereby streamlining the process. Scenario 2 further eliminates the curing time at Saab, contributing to additional efficiency gains and reduced environmental impact.

4 Discussion

4.1 Effectiveness and usability of the ECD methodology

The results of this study indicate that the Environmentally Conscious Design (ECD) method is a valuable tool for identifying environmental improvement opportunities during product redesign. By providing a structured framework for assessing environmental impacts throughout the product life cycle, the method guided discussions toward sustainability issues that might otherwise have been overlooked. The application of the ECD method successfully identified critical environmental aspects and formed the basis for targeted design improvements, demonstrating its potential to support more sustainable product development.

Despite its overall effectiveness, several challenges were identified during the application of the method. The most significant challenge concerned the interpretation of environmental criteria. Many criteria were perceived as similar and difficult to distinguish, resulting in overlapping discussions and repeated improvement suggestions. In addition, some criteria required environmental data that was not readily available, making the assessments more dependent on expert judgement than quantitative evidence. These limitations reduced the consistency of the evaluations and affected the prioritization process.

The findings suggest that the usability of the ECD method could be improved by simplifying the criteria, reducing overlap between assessment categories, and providing clearer examples, and preparatory material before workshops. Better participant preparation would likely increase confidence in the assessments and improve the quality of discussions.

4.2 The role of ECD in product development

Although some of the resulting design improvements might have been identified using other engineering methods, the ECD method's primary contribution was its structured approach to identifying environmental priorities and defining the problem. The systematic evaluation of the product life cycle encouraged discussions that may not otherwise have taken place and provided a clear environmental rationale for focusing on specific improvement areas. This framework guided subsequent interviews, problem identification, and concept generation, ensuring that sustainability remained central throughout the redesign process.

The study also indicates that the ECD method has strong potential to be integrated into Saab's product development process, particularly during the early concept and design phases where environmental priorities can influence major design decisions. Beyond functioning as an assessment tool, the criteria could serve as a design framework that encourages multidisciplinary teams to incorporate sustainability considerations throughout product development. However, a significant challenge lies in the limitation of detailed data during these early stages, making it difficult to fully satisfy all environmental criteria and balance them against rigid technical constraints. Despite these initial limitations, integrating the method more broadly within Saab could help identify additional improvement opportunities that might otherwise remain unnoticed and strengthen sustainability as a natural part of engineering decision-making.

Although it was initially stated that component C1AI was restricted, including it in the interviews proved highly valuable. This demonstrated that discussing even a sensitive and restricted component can yield significant environmental benefits; while the C1AI component itself remained unchanged, the dialogue triggered innovative ideas to optimize the surrounding components and interfaces attached to it. This highlights that eco-design evaluations should not be limited by rigid technical constraints, as systemic improvements can still be achieved through secondary adjustments.

By applying Saab's ECD method to the G1X radar system, this study demonstrates that environmental improvements do not have to be a financial burden on the industry. The redesign of the cable holders at component C1AI led to both reduced environmental impact and direct benefits such as shorter assembly times, lower material costs, and a safer working environment. In this way, the project counters the assumption that sustainable design is merely an expense, showing instead how strategic environmental efforts can serve as a direct efficiency improvement.

4.3 Addressing the research questions

The first research question examined whether the ECD methodology can identify sustainability improvement opportunities in an existing Saab product. The results show that the method successfully highlighted key environmental challenges and generated prioritized improvement areas throughout the product life cycle. However, the findings also indicate that the method relies on participants having sufficient environmental and product-specific knowledge to achieve meaningful outcomes.

The second research question focused on how these opportunities could be translated into design improvements. The ECD process supported this transition by generating practical design concepts, including reduced adhesive use, increased recycled materials, improved design for disassembly, and simplified manufacturing. While these concepts demonstrate the method's potential, further technical and economic evaluation is required before implementation.

4.4 Integrating environmental and social sustainability

The findings also show that ECD encourages broader and more innovative discussions than a conventional redesign process. By applying a backcasting approach, participants considered long-term sustainability goals rather than only current technical limitations. Finally, the results suggest that the proposed improvements contribute not only to environmental performance, but also to improved ergonomics, safer working conditions, and more efficient manufacturing. As argued by Broman and Robèrt (2017), long-term sustainability depends on maintaining both ecological and social systems. The findings support this perspective, showing that the ECD method enabled design improvements that reduced environmental impacts while improving worker safety and ergonomics. This highlights the importance of considering both environmental and social sustainability early in the product development process.

Social sustainability is often poorly defined within organizations and is frequently managed through compliance with regulations rather than proactive product development (Lagun Mesquita, 2021). As a result, responsibility for social sustainability is commonly limited to functions such as Human Resources and Environmental Health and Safety, with little integration into engineering design or strategic decision-making. This contrasts with the findings of this study, where the ECD method encouraged consideration of both environmental and social aspects during product redesign. The identified improvements, including enhanced ergonomics and safer working conditions, demonstrate that integrating social sustainability early in the design process can generate value beyond regulatory compliance. Social sustainability should be embedded in product development and organizational decision-making rather than being treated as a separate compliance issue.

4.5 Limitations

The study was limited to resulting in design proposals without detailed manufacturing and cost-analysis, and additional LCA analysis. Future research should address these limitations by conducting a more comprehensive LCA and exploring additional data.

During the workshop and interviews, it was clear that more detailed knowledge about the product and its subcomponents was needed to lead the workshop and the discussions. A deeper understanding of the functionality of the product and deeper environmental knowledge would have allowed more specific questions to the experts. There were also gaps in data gathering and gaps in data for final concept validation, particularly regarding manufacturing data.

Furthermore, the final concept validation was constrained by gaps in data gathering. The lack of empirical manufacturing data limited the ability to fully quantify the concept's actual production impact, meaning certain conclusions had to rely on theoretical estimations rather than concrete industrial data.

Another significant limitation during the study was the challenge of gathering data due to company confidentiality and corporate security regulations. Because the project involved highly sensitive information, access to certain technical and financial data was restricted. Furthermore, the complexity of the radar system made it difficult to fully comprehend all technical interdependencies within the given timeframe. Additionally, the high technical complexity of the product, combined with strict restrictions on sensitive data, made it difficult to fully comprehend and communicate about the system.

4.6 Suggestions for future development

To transition from theoretical frameworks and early-stage design concepts into full-scale industrial implementation, several critical areas must be investigated further. Future research should focus on validating the preliminary environmental and manufacturing assumptions with empirical data, ensuring financial viability, and embedding these eco-design principles into the organizational routine. Consequently, the following steps are recommended for future development:

1. Comprehensive LCA: Conduct a complete LCA for the proposed design concepts.
2. Cost analysis: Perform a detailed cost analysis of the proposed design concepts.
3. Prototyping and testing: Develop prototypes and conduct functional testing.
4. Integration into Saab's processes: Integrate the ECD methodology into standard product development processes.

5 Conclusion

The research questions were successfully answered through the application of the proposed methodology:

- **RQ1:** The ECD methodology was successfully applied to identify and prioritize environmentally critical improvement areas in the G1X radar system.
- **RQ2:** The identified improvement areas were translated into design concepts that reduce environmental impact while maintaining social sustainability, product performance, and functional requirements.

The proposed design concepts, which integrate cable holders into the frame, reduce environmental impact while improving social sustainability, product performance, production efficiency, and working conditions. The validation process confirmed the feasibility and potential of these solutions.

The findings provide Saab with a structured approach to integrating sustainability into product development. The ECD methodology successfully identified and prioritized environmentally critical improvement areas in the G1X radar system, while backcasting supported the identification of root problems and the development of future-oriented solutions. Together, these methods enabled the development of concepts that reduce environmental impact without compromising social sustainability, economic viability, product performance, or functional requirements.

This research demonstrates that the combination of ECD and backcasting is an effective approach to sustainable product development. ECD provides a systematic framework for identifying and evaluating environmental improvement opportunities, while backcasting supports the development of long-term sustainable solutions by addressing root causes and defining desirable future states. The study highlights the value of integrating sustainability considerations early in the design process, enabling the development of more sustainable, efficient, and future-oriented industrial products and manufacturing systems.

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7 Appendix

Appendix A: Summarised survey results

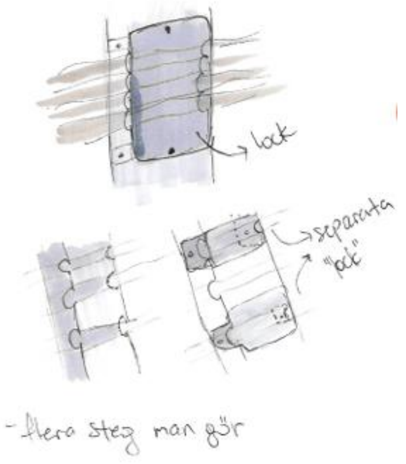
1) Did you feel that the” Back casting part / visioning” at the beginning made it easier to see long-term solutions?
   Most respondents found the backcasting part helpful in broadening their perspective and encouraging creative thinking. However, some felt limited by the need to focus on feasible solutions rather than purely imaginative ones.
2) What was the biggest challenge with using this method today? (Both ECD criteria and Back casting)
   a. Scope management: Difficulty in staying focused on the specific product rather than expanding to broader areas.
   b. Understanding criteria: Some ECD questions were difficult to understand or differentiate, and certain metrics were hard to contextualize.
   c. Knowledge gaps: Lack of sufficient knowledge about processes and materials that contribute to environmental impact.
   d. Subjectivity: Setting percentages for progress was seen as highly subjective.
3) On a scale of 1 (not likely) – 5 (very likely), how likely is it that you would want to use this way of working again?
   One person answered 3, two persons said 4 and two of them answered 2.
4) Was there any moment you found valuable for identifying improvements? If yes, which one?
   a. Detailed discussions: Going through questions one by one provided relevant solutions.
   b. Open discussions: Encouraged sharing of knowledge and perspectives.
   c. Diverse competencies: The mix of expertise in the meeting was highly valued.
5) Was there anything in the ECD methodology itself that felt complicated to understand?
   a. Metrics and questions: Confusion over the basis of certain numbers and the similarity of some questions.
   b. Criterion selection: Uncertainty about how final criteria were prioritized.
6) Do you believe that this way of working will lead to actual improvements for SAAB?
   a. Positive outlook: Most respondents believed it could lead to improvements, especially if received with an open mind.
   b. Awareness and compliance: Even if direct changes are minimal, increased awareness and compliance with environmental standards were seen as valuable.
   c. Economic incentives: One respondent noted the lack of economic incentives as a potential barrier.
7) Do you have any other feedback or final thoughts for us?
   a. Appreciation: General appreciation for the workshop and the effort put into planning and execution.

b. Encouragement: Encouragement to continue challenging traditional methods and seeking innovative solutions.

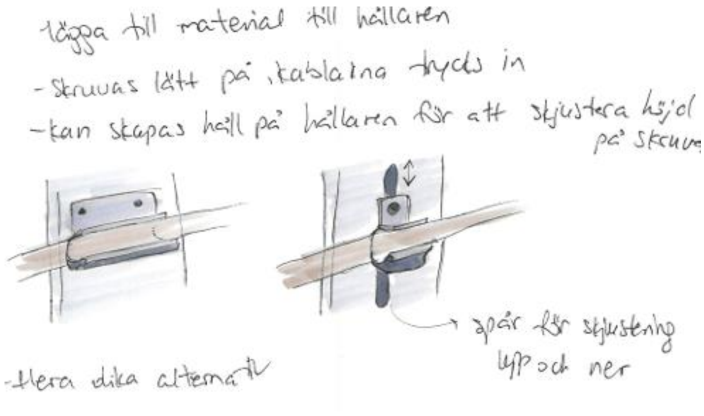
Appendix B: Observation

1. Surface preparation:
    - Scrape the circular surface on the C1AI and the underside of the holder.
    - Scrape in all directions for better adhesive bonding.
2. Cleaning:
    - Clean with cotton swabs dipped in ISO propanol to remove steel dust.
3. Bonding the holder:
    - Apply adhesive to the underside of the holder and glue it to the C1AI.
    - Press down the holder so that adhesive squeezes up around the edges.
4. Curing:
    - Move the C1AI for 24 hours of curing.
    - Apply adhesive through the glass to avoid inhaling adhesive fumes.
5. Protecting the work surface:
    - Place paper around to protect it from adhesive.
    - Use extra paper to wipe adhesive from gloves – remember to change gloves every 10 minutes.
6. Mixing the adhesive:
    - Use a scale and a plastic bowl to mix adhesive from two containers.
    - Mix until the adhesive is homogeneous.
7. Filling the syringe:
    - Fill the syringe with adhesive using a thin wooden stick.
    - Fill a double amount to ensure there is enough.
8. Using the press machine:
    - Connect the syringe to the press machine with a foot pedal.
    - Adjust the pressure as needed.
9. Bonding the first holder:
    - Apply adhesive to the underside and press the holder down.
    - Apply adhesive in circles around the holder, smooth it out, and brush away bubbles.
10. Bonding multiple holders:
    - Glue the holders located farther inward on the C1AI first.
    - Stay focused to avoid mistakes.
11. Inspection:
    - Inspect the adhesive using a mirror.
    - Correct any defects before curing.
12. Bonding ferrites:
    - Glue the ferrites in place.
13. Curing:
    - Leave the C1AI in the fume cabinet for 24 hours.
14. Final curing:
    - Leave the C1AI in another cabinet for about one week (5 days).

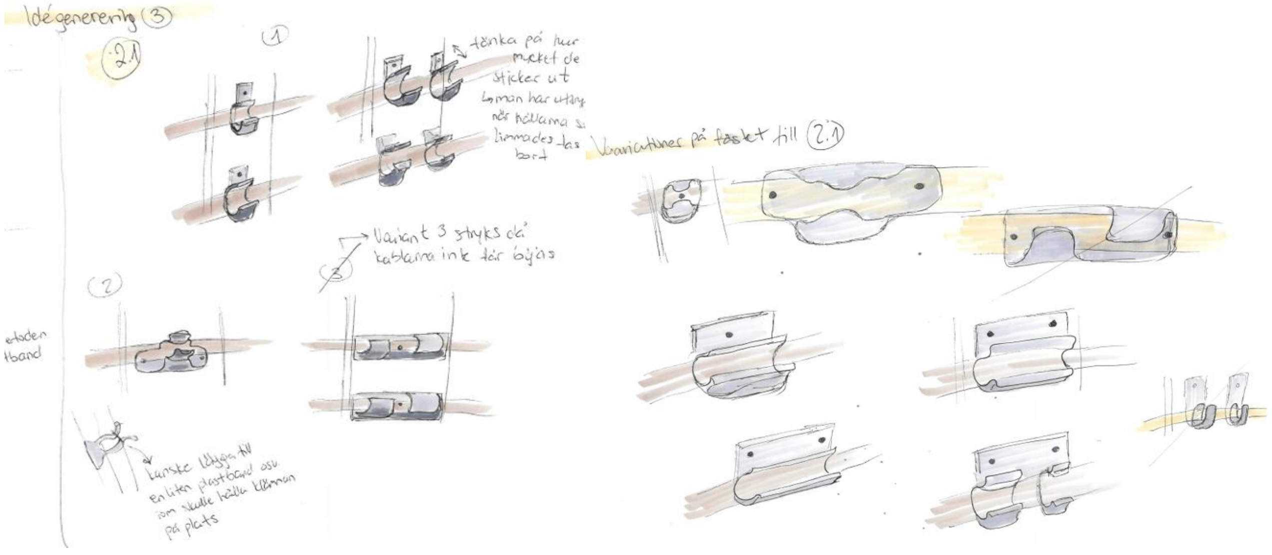
Appendix C: Details of Concept 1



Appendix D: Details of Concept 2



Appendix E: Several solutions of fastening cables for concept 2



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