SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V13I5P103

Volume 13 Issue 5, 34-44, May 2026
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*Original Article*

# Integration of Ecodesign and Life Cycle Assessment with ISO Framework for Product Environmental Sustainability

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Received: 06 February 2026 Revised: 12 March 2026 Accepted: 15 April 2026 Published: 29 May 2026

***Abstract*** *- Life Cycle Assessment (LCA) methodology in the design process allows product engineers to improve product sustainability by knowing the hot spots of environmental impacts. However, early integration of Life Cycle Assessment (LCA) into the conceptual stage of product designers is often challenging. The challenge will become more difficult when the product engineer uses the LCA approach to collaborate with the industrial designer for the assessment of ecodesign concepts to mitigate adverse environmental impact issues, as design keeps constantly changing to arrive at a better concept. This study proposes a methodology to integrate eco-design and Life Cycle Assessment (LCA) with the ISO 14006:2020 framework as early as the eco-design conceptual stage. The aim is to provide the "Eco-design LCA (ED-LCA)" assessment feedback to the industrial designer and the product engineer so as to mitigate the environmental impacts through concept sketch or concept design. The proposed study is expected to help establish better collaboration between the industrial designer and product engineer, so as to design an environmentally friendly product with an eco-design LCA approach.*

***Keywords*** *- Eco-design, Conceptual Design, Industrial Design, Ecodesign Life Cycle Assessment, Product Design, Design Collaboration.*

## 1. Introduction

Product environmental sustainability is a continuous collaboration between designer and engineer, whereas it is not achieved by design or engineering alone. Product development is an iterative process and hence needs collaboration between the industrial designer and product engineer during early concept development. Industrial designers' design decisions drive a product's environmental impacts, but without engineering validation, these design decisions are not feasible. Hence, to achieve product environmental sustainability, the collaboration between designer and engineer is a must at the conceptual level.

The industrial designer working on products generally conducts market research (color, form, finish, material, and trends) and user research (behavior, ergonomics, aesthetics, and surveys) to understand the pain points while the product is being designed. From market and user research, ideation starts, and conceptual sketches are developed. With rigorous review of marketing, concept sketches are reviewed, and the selected concept will be 3D rendered. The main objective of the industrial designer is to develop geometry with a focus on form and aesthetics. These 3D rendered images, CAD files (mainly surface files), are then submitted to the product engineer to continue with the product development. The role of a product engineer starts from these 3D renderings received from an industrial designer. This is a common practice followed in the consumer durables industry. The information and communication between these two requires accounting for the environmental impact of the concept sketches (industrial designer) and the eco-design concept (product engineer). There needs to be a feedback loop for better collaboration, and hence, authors in this study have proposed an Eco-design LCA (ED-LCA) approach for better collaboration. The ED-LCA will be carried out with any existing widely used LCA tool available, with more focus on material, energy used during the use phase, manufacturing method, packaging design, and end-of-life scenarios. The focus is mainly on the design aspects of the product rather than the operational side, i.e., during the distribution phase, because of time constraints to launch the product in the market. However, product design is an iterative process where the material selection, manufacturing methods, design concepts, and factors continuously evolve, and hence require an agile Life Cycle Assessment (LCA) approach for effective integration throughout the design process [3]. Most of the researchers have incorporated the LCA approach at the early stage of concept design, but this lacks a collaborative approach, and most of the time, the LCA is conducted by the product engineer. The industrial designer's role for the environmental impact also needs to be addressed, as 3D renderings are the basis for a product engineer to carry out concept design. The LCA approach methodology should be

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addressing environmental issues at the early design stages, as it is crucial when aiming for more radical environmental improvements [4].

The aim of this study is to address the much-needed collaboration required between an industrial designer (marketing) and a product engineer (R&D) by an Ecodesign LCA (ED-LCA) methodology to address the environmental issues at early design stages of product development.

## 2. Literature Review

The integration of ecodesign and LCA within the ISO framework has become a foundation to achieve product-level environmental sustainability. Ecodesign focuses on environmental considerations at early design stages, LCA evaluates environmental impact across the entire life cycle of a product, and ISO 14040 & 14044 establishes a methodological foundation for LCA. Several challenges in applying LCA in early design stages are due to limited data availability, uncertainty, and the complexity of the assessment tool. The standardized LCA methodology and practical design workflow should be taken into consideration by industrial designers and product engineers while making design decisions. Recent literature emphasizes that combining ecodesign with LCA enables more informed decisions during product development.

*Malte Schäfer and Manuel Löwer (2024)* reviewed 106 existing ecodesign review articles and examined the increasing trend in recent publications regarding ecodesign and the LCA approach, and summarized the findings. This trend reflects a growing number of ecodesign review articles published over the years. The authors extracted 608 statements related to the research question, covering ecodesign terminology, evolution, barriers and success factors, methods and tools, and synergies with other research disciplines. *Matilda Watz et al. (2022)* presented an evaluation of the PROSEQ profile model, developed to support product development organizations in enhancing sustainability integration into engineering requirements and improving their sustainability through a requirements-based perspective. *Mendes da Luz L et al. (2018)* proposed a methodology of integrating LCA into early stages of product development, from the planning stage to product review, with six stages in the product development process. The authors developed a qualitative assessment matrix for LCA integration in the PDP process. *Seow et al. (2016)* proposed a methodology to minimize the energy consumption in the phases of conceptual design, detail design, and production by Design for Energy Minimization (DfEM). D.C.A. *Pigosso et al. (2015)* established LCA as a robust tool to support decision making and communication of environmental performance of products; with the increased focus on end-of-life strategies, and with the understanding that the highest opportunities for increasing the environmental performance of products were in the initial stages of product development.

From the literature review, it is obvious that ecodesign is considered early in the product development process. The LCA integration is also carried out at the early phases of the product design and development process to know the environmental hotspots and take corrective actions. However, there is a need to connect prior to the product design and development process (product engineer), to know where their input is coming from, customer demand, and or through market research (industrial designer). There is a need to translate these customer demands through design into the product as early as the design phase to radically reduce the environmental impact of the product. Hence, there is a need for collaboration between the marketing department (industrial designer) and the Research and Development department (product engineer) through the ISO framework. The aim of this paper is to address this important concern of collaboration by integrating ecodesign and LCA integration with the ISO framework to radically reduce environmental impacts by identifying hotspots and taking corrective actions by both, i.e., the industrial designer and the product engineer.

The extant literature provides limited evidence on how to incorporate an ecodesign into sketches or initial concept design sketches from the industrial design point of view. *Tejaswini Chatty et al (2024)* presented a digital sustainability tool, EcoSketch, to address LCA applicable to early-stage product development and accessible to non-expert users. The authors tried to embed the environmental impact into the sketch or ideation stage itself. *Donnici, G et al. (2025)* presented Stylistic Design Engineering (SDE) and the capabilities of generative AI. The study investigated how AI accelerates design processes such as ideation, style analysis, and development by generating design variations and refining concepts into digital models. Generative AI sketching tools accelerate the ideation process by generating multiple design variants in a short period of time. *Bakırlıoğlu, Yekta et al. (2012)* introduced a generative tool called Biomimicry Sketch Analysis (BSA) and provided an assessment criterion on how it should be incorporated in achieving sustainable design considerations. *Xavier Marsault and Florent Torres (2019)* presented an 'EcoGen2.1' tool to the building simulation community, which is adapted to the sketch step of the design. They focused on developing real-time interactive software for generative eco-design in the early stages of an architectural project. *Q. Lou et al. (2024)* propose three designer-AI collaboration modes with typical operable processes during sketching, with focus on the sketching stage that mainly contributes to bridging the theoretical research and design practice regarding designer-AI collaboration. *Philip J. Farrugia et al. (2007)* present ongoing research on a portable sketch-based tool that enables designers to generate and share 3D CAD models from paper sketches using camera phones.

Hence, concept sketches as part of the ideation in industrial design play an important role in environmental sustainability. These concept sketches were used in the form of 3D rendering by the product engineer to design ecodesign concepts. There should be a talk-back or communication loop, a feedback mechanism, or collaboration required to assist the concept sketches and renderings, which will be the best fit to reduce environmental impact. *Lofthouse (2004)* provided empirical evidence to support the theory that there is a specific and valuable role for core industrial designers working at the operational end of ecodesign and presented the first detailed understanding of what this role involves. Also, providing them with the capability to implement ecodesign at the operational stage can significantly increase the likelihood of eco-designed products reaching the market. The aim of the present study is to develop an integration methodology of ecodesign, LCA, and the ISO framework, and a talk-back or collaboration between the industrial designer and the product engineer.

## 3. Proposed Methodology

Ecodesign means a systematic approach that integrates environmental considerations into product design and development to minimize negative and increase beneficial environmental impacts throughout the life cycle. Ecodesign means considering environmental considerations at each stage of the design process [16]. Applying Life Cycle Assessment (LCA) during the design phase is essential for successfully developing products with optimized environmental performance [3]. Some studies suggest that an ecodesign expert should be involved in design decision-making, where needs are evaluated, prioritized, and refined into initial requirements [5]. If the aim of a product engineer is to design environmentally friendly products, then integration of ecodesign and LCA approach early at the conceptual stage of product development will help. There is an added advantage if this integration has been done with the *ISO* framework. In this section, the current practices of LCA, the proposed integrated LCA methodology, the product life cycle phase, and the ISO framework are discussed with the aim of ecodesign concept development.

### *3.1. Current Approach (LCA, Product Life Cycle, and ISO 14044)*

Figure 1 shows the traditional LCA methodology, which is carried out after the product launch, because by that time, operational supply chain routes are finalized, and it helps in the collection of more accurate data for environmental impact analysis. A typical product life cycle has input (energy, raw materials, water, etc.) and has an output (product, byproduct, emissions, health & safety impacts, etc.) The output has an impact on human health, damage to ecosystems, and damage to resources. These outputs need to be quantified to know the damage and should have a control plan to reduce these impacts by redesigning the existing product or rerouting the supply chain. To know these impacts, LCA is carried out as per 'Environmental management- Life cycle assessment-Requirements and guidelines (ISO-14044).'

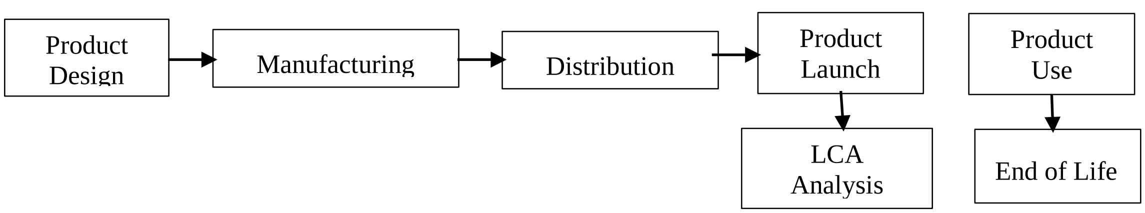


**Fig. 1 Traditional LCA methodology**

The LCA starts with a goal and scope definition of the ISO 14044 framework to define the system boundary (cradle to gate, cradle to grave, etc.). The inventory analysis in terms of ($CO_2$, PFCs, SF6, $N_2O$, HFCs, CFC-11, NOx, $SO_2$, KJ or Watt, Litre, etc.) is collected from the design stage to end-of-life, based on the predefined system boundary. Then this inventory analysis is quantified against impact categories (Global Warming Potential, Ozone Depletion Potential, Eutrophication, Acidification, land use, etc.) in terms of kg $CO_2$ eq by using various methods (Recipe, CML, TRACI, ILCD, etc.) offered by LCA tools (Open LCA, SimaPro, GaBi, etc.). The quantification and analysis are carried out at each stage of the product development process. From these LCA, environmental hotspots are identified, and corrective design, manufacturing, or supply chain action is then taken to reduce the environmental impact caused by a particular process. However, as most of the LCA studies are carried out after the launch of the product, and in such situations, industrial designers and product engineers have no option but to revise or update the design. Once the design is released for production, there is very little control by the engineer. Later organizations try to reduce environmental impacts by doing scope 1, 2, and 3 analyses.

The authors tried to integrate the LCA analysis with ISO 14044, product life cycles, and environmental impact categories, and highlighted the traditional LCA stage as shown in Figure 2. One can understand from Figure 2 that, at later stages of the product development cycle, the traditional LCA is carried out. There are a lot more prior stages available in the product development cycle, and the LCA analysis can be carried out with these prior stages, as early stages are of greatest importance to negate environmental impact. However, traditionally, the LCA is carried out after the launch of the product, along with the use phase, and the end-of-life stages of the product life cycle. The traditional LCA is not carried out at the conceptual stage or in prior stages of the product life cycle.

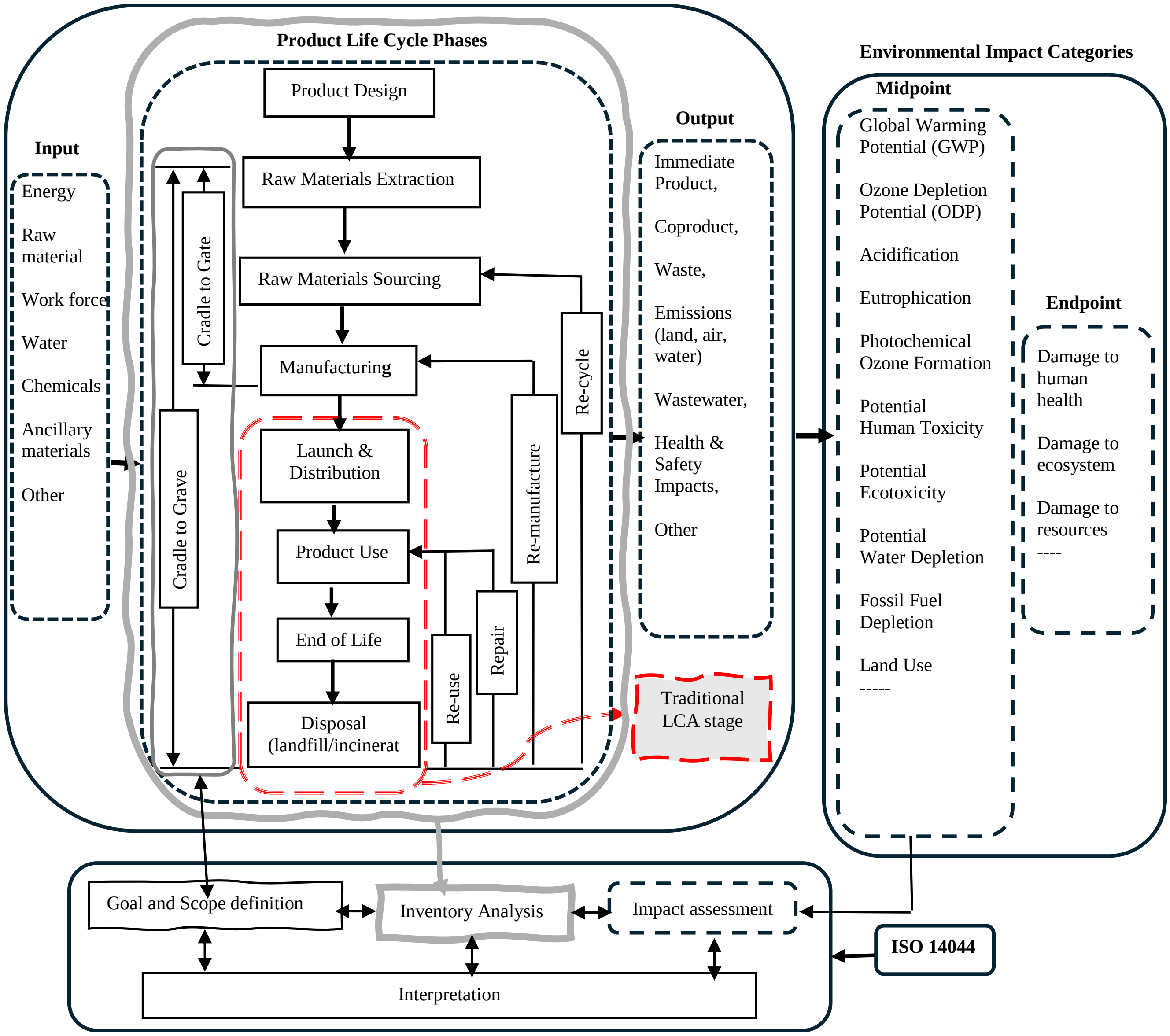


**Fig. 2 Integration of product life cycle phases, LCA, impact categories, and ISO 14044**

### *3.2. Proposed LCA approach (ED-LCA, Ecodesign, and ISO 14006:2020)*

Legislation, code of conduct, government policies, demanding energy labels, and customer demand associated with product-level environmental impacts (eco products) are evaluated in most organizations. Such organizations require methodologies or guidelines to develop and implement a systematic approach to ecodesign products. Figure 3 shows the integration of LCA between the industrial designer and the product engineer within the framework of 'Environmental management systems- Guidelines for incorporating ecodesign (ISO 14006:2020)' standard. Research indicates that involving the industrial designers in the product development can enhance ecodesign products through their diverse skills and broad knowledge base, as they translate product ideas into concrete ideas. They also go beyond technological solutions by considering user psychology through behavioral studies [15]. Industrial design often determines ergonomics and appearance, visualizes the product concept, and generates alternate design solutions. Industrial designers are often referred to as 'people-centered, generalists, market-oriented & product software' while product engineers are referred to as 'technology-centered, specialists, technology-oriented & product hardware' [22, 23]. Industrial design contributes to new product concepts, development, and detailing by providing strategic and creative input; however, they are rarely involved in the early-stage decision-making [24]. Industrial designers can be viewed as a bridge between the market and technology, remaining closer to the market needs and acting as a front end, while product engineers focus on technical and production-related aspects.

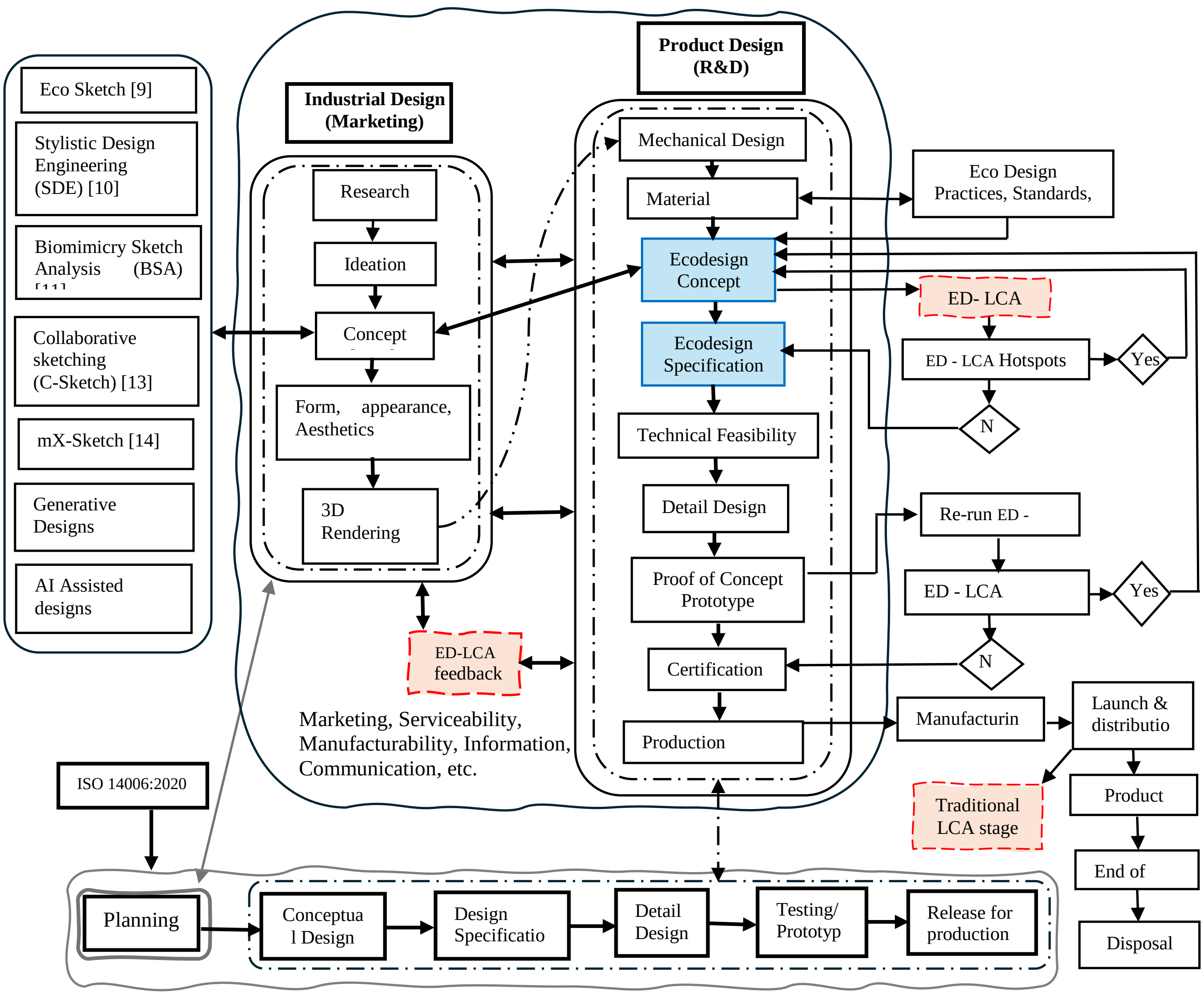


**Fig. 3 Proposed methodology for ecodesign, LCA approach with ISO 14006:2020 framework for New Product Development (NPD)**

Industrial designers are primarily responsible for the overall appearance and user experience of a product, while ensuring the concept design is effective and successful [22]. Hence, it is proven knowledge that the contribution of an industrial designer is huge in product development. Therefore, it is the need of the hour to collaborate with them for better ecodesign concepts, which will help negate adverse environmental impacts. Most literature discusses generic design and those referred to product design, and hence, industrial design's ecodesign relationship is little understood [24].

As shown in Figure 3, the authors tried to bridge this gap of collaboration and relationship during the early stage of product development with the framework of ISO 14006:2020 for ecodesign product life cycles. Through proper market research, the industrial designer develops concept sketches from the pain points of the product under study, and from these concept sketches, 3D renderings with form and appearance will be developed. Then these 3D renderings will be handed over to the product engineer to transfer them into a mechanical design (manufacturability, serviceability, mass production, product compliance, etc.). The typical mechanical design follows traditional product design and development processes, whereas the authors in this study are suggesting adding two typical stages, such as "Ecodesign Concept" and "Ecodesign Specification," with the framework of ISO14006:2020, as shown in Figure 3.

During the Ecodesign concept, the LCA analysis is carried out, and authors referred to it as Ecodesign Life Cycle Analysis (ED-LCA). The ED-LCA should be carried out based on seven important metrices available as discussed in section 3.2.1, as during this phase of product development, supply chain routes are yet to be finalized. The hot spots identified during the ED-LCA should be used to modify the ecodesign concept and the ED-LCA feedback given to the industrial designers to modify concept sketches for further improvement in form, finish, material, and style, etc. The common guidelines for industrial designers should be surface area to volume ratio (A/V), Length To Diameter Ratio (L/D), user behavior, trends, and material density, to name a few, to have improved concept sketches or 3D renderings.

There should be constant collaboration between these two (the industrial designer and the product engineer) with respect to manufacturability, serviceability, branding, cost, styling, trends, user behavior, and anthropometric, etc., to update ideation or redesign the renderings so that the concept sketches will become concrete eco sketches. This collaboration resulted in an improved ecodesign concept for the product engineers. Once the ecodesign concept is developed, the ecodesign specification documents should be updated, which act as a future reference for products to be developed. Once the technical feasibility is completed, the detailed design should be carried out, and a proof-of-concept prototype should be made.

Re-run the ED-LCA on the proof-of-concept prototypes to identify any hidden hot spots that were missed during ecodesign concept development. The ED-LCA feedback from the proof-of-concept prototype was again reviewed with the industrial designer to modify or update the concept sketches to arrive at satisfactory ecodesign concepts. Thus, an industrial designer integrates market needs with technology. The re-run ED-LCA, on the proof-of-concept prototypes, should be conducted with broader teams, including manufacturing, production, and supply chains, for improvements in the life cycle of the product to reduce environmental impact. This collaborative approach to designing products that negate the negative adverse environmental impact is crucial to having eco-friendly products. The next steps are to certify the product based on regulatory or compliance requirements as necessary and release it for production.

*3.2.1. Ecodesign Concept and Ecodesign Specifications*

Authors refer to LCA analysis as Ecodesign LCA (ED-LCA), because during the conceptual stage, LCA analysis, and product distribution phases are not considered. In the ecodesign concept, the environmental focus should be on emissions, toxicity, or circular designs with the focus on seven impact metrices as shown below, which ensures that the life cycle thinking is applied in the product design and development at the conceptual stage.

1. Material selection
2. Component geometry
3. Packaging design
4. Product Use
5. End of life
6. Design for R (reuse, reduce, remanufacture, repair, refurbish, recycle, redesign, rethink, repurpose, etc.)
7. Design for X (assembly, disassembly, manufacture, cost, safety, modularity, disposal, reliability, etc.)

Material selection, component geometry, energy consumption by product, product use phase, packaging design, and end-of-life scenarios can be designed considering ecodesign practices. For material transport, existing supply chain routes can be considered. The authors do not recommend a new tool in this study for LCA analysis. One can use existing tools and run LCA considering eco design concepts, product use, and end-of-life scenarios, or use GHG protocol emission factors to know the sustainability impact. Authors used the GHG protocol emission factors to know the sustainability impact through a case study, as at the initial stages, it is well-suited for seven impact metrices. The ED-LCA can be calculated by multiplying the material quantity by the emission factor of that material.

$$\text{ED-LCA}_{\text{product}} = \sum_{i=1}^{n} [M_i \cdot EF_i] \tag{1}$$

OR

$$\text{ED-LCA}_{\text{product}} = (M_1 \text{ x } EF_1)+(M_2 \text{ x } EF_2)+\ldots\ldots\ldots+(M_n \text{ x } EF_n) \tag{2}$$

Where,

$\text{ED-LCA}_{\text{product}}$ = Total GHG emissions of the product (kg $CO_2$e)
$M_i$ = Mass of the *i*-th part (kg)
$EF_i$ = Emission factor of the *i*-th part (kg $CO_2$e/kg)
i = Part index (1,2,3,….. n)
n = Total number of materials or parts in the concept.

The ecodesign concept gives overall product dimensions, material quantity required, overall packaging dimensions, design for end-of-life scenarios, estimated energy consumption during the use phase, design for R and X implementation, etc. These data are sufficient at the conceptual level to carry out the ED-LCA. The only thing left in this is operational side data quantification. Existing similar product operational side data can be referred to arrive at the overall LCA results. Doing ED-LCA at the conceptual stage gives an important advantage to designers to update or modify their design to be best suited for environmental benefit, as once the drawings are released for production, the designer and or engineer has less control over them to modify or update, or else it becomes costlier to update them.

*3.2.2. LCA Approach for Product Redesign and Product Improvement for Existing Products*

Ecodesign should be implemented in both new product development and the redesign of existing products, including necessary process modifications for their delivery [21]. Figure 4 shows the methodology for a product redesign and product improvement. It is essential to have LCA data of existing products to benchmark and make improvements. The authors tried to put methodology in place to redesign the existing products with a collaboration approach between industrial designers and product engineers. The guidelines were shown in Figure 4 to design products with improved environmental impact. After LCA analysis of existing products, the opportunity identification step is the most important, and guidelines for opportunities are shown in Figure 4. With these opportunities, form, shape, and aesthetics need to be redesigned with the help of an industrial designer. Ecodesign targets are set against identified opportunities and achieved through the redesign or supply chain rerouting. Based on the targets, ecodesign specifications were developed to achieve these targets throughout the product development cycles. Later, from these specifications, the ecodesign concept developed.

From the ecodesign targets, the ecodesign specification needs to be documented to benchmark for future similar product applications. These specifications act as a guideline and reference to avoid adverse environmental impacts, and they save time in future product development. The ecodesign concept can be modified with the collaboration of the industrial designer, and ecodesign specifications will then be updated. The communication and information flow, such as marketing approvals, serviceability, and manufacturability, are the important criteria for ecodesign concept development with the industrial designer and need constant collaboration.

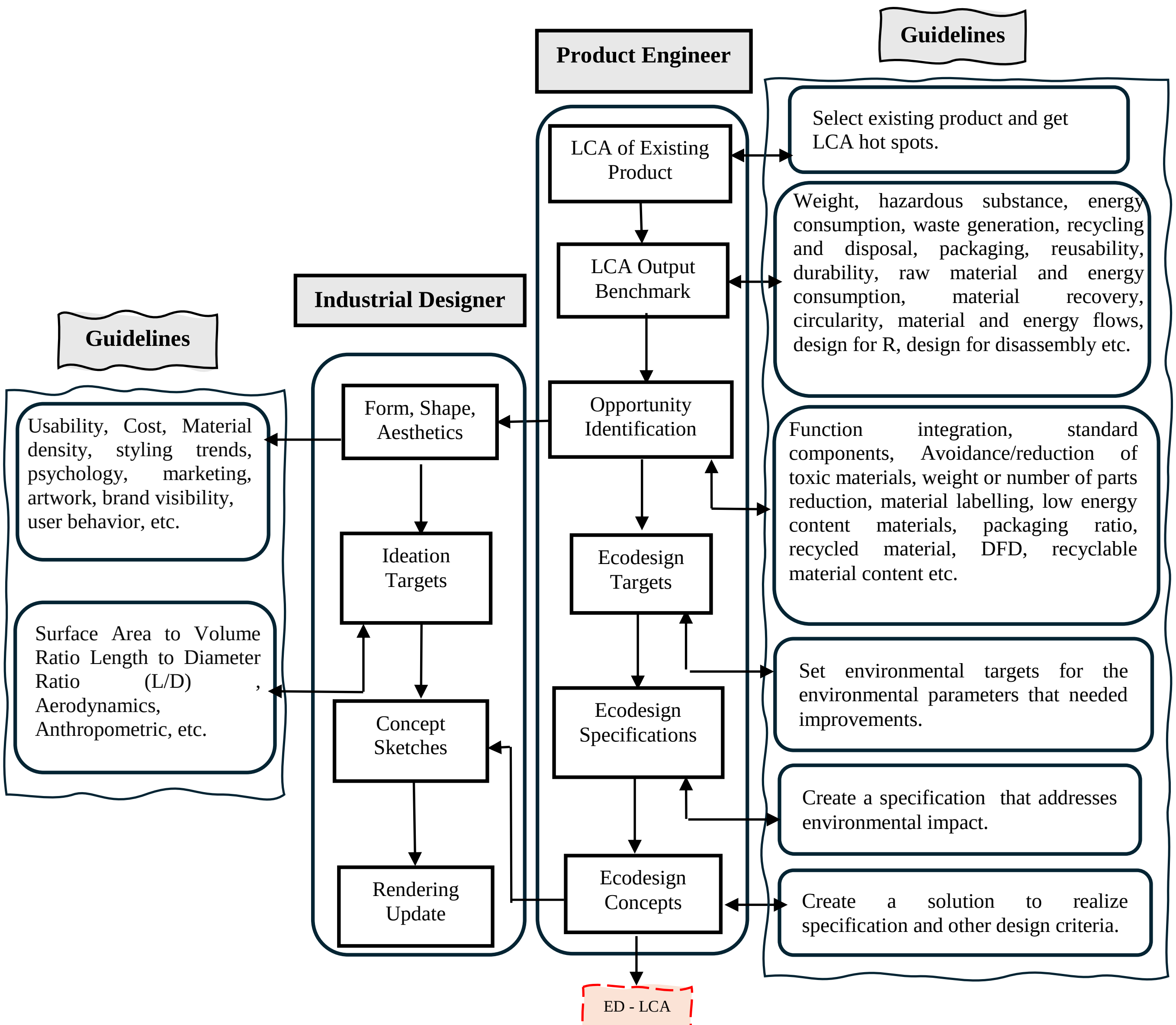


**Fig. 4 Proposed methodology for product redesign and product improvement**

Ecodesign concept was developed by choosing environmentally friendly materials and guidelines, such as renewable, biobased, quantity and variety (dematerialization, lightweight, nanomaterial strategy, similar, few different, varietal purity, reduce thickness, etc.), recyclability & reusable, long lasting, compliance (RoHS, REACH, WEEE, SVHC, etc.). Component Geometry can be optimized through quantity & weight reduction, modularity & simplicity (simplify modules, make variants easily replaceable), reduction & recyclability (elimination, substitute or redesign, reduce part count), standardization, integration, and multifunctional parts.

During the product use phase, the design should aim to avoid standby losses, use a default power down mode, design for lower energy consumption, and minimize harmful emissions during the product use phase, etc. End of life scenarios like design for disposal, design for R (recycle, reuse, remanufacture, etc.), design for safety, design for disassembly, design in compliance with product retrieval system, identification of disposing methods, manuals, labels, self-repair kits, codifying materials to facilitate their identification, indicate material age, number of times recycled, existence of toxic material, and additives used are taken into consideration. Packaging Design aims to provide eco-friendly packaging and alternative materials. Energy consumption and materials are linked to smaller, lighter products.

Once the product engineer develops the ecodesign concept from the updated renderings received from the industrial designer, for the product to be redesigned, then the ED-LCA is carried out, and hotspots are identified. If identified hotspots required major changes in 3D rendering, then the design feedback is sent to the industrial designer so that concept sketches can be modified to negate adverse environmental impact. The renderings must be approved by marketing for the winning product in a market. Concept sketches, with the help of AI assistance, can immediately generate generative designs, and the environmental impact can be assessed at the sketch level based on geometry and material density after the ED-LCA is carried out on these ecodesign concepts to know environmental hotspots, and then follow the methodology from the ecodesign concept stage, as shown in Figure 3, to arrive at a better proof of concept. The collaboration is a must between the industrial designer and the product engineer at these stages.

## 4. Case Study

The case study of a typical water heater's new product development has been discussed in this section. The industrial designer developed an initial sketch of a water heater as shown in concept ‘a ’ with a Length To Diameter Ratio (L/D) of 1.8, in Figure 5. The knob was in the center with a green light (Power ON) and a red light (Heating ON) to know user about the status of the water heater. The concept ‘a ’ has the potential to revise the concept sketches, as it requires a longer length of power cord to

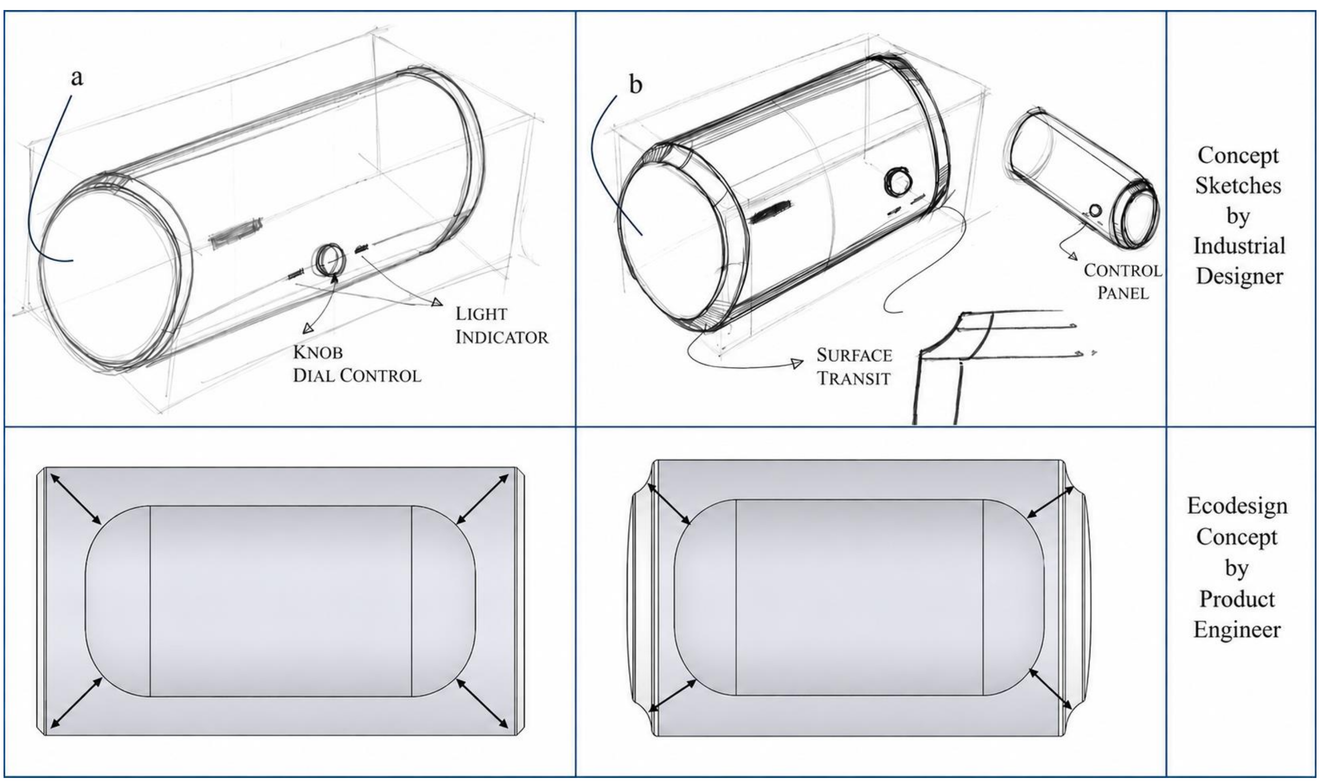


**Fig. 5 Concept sketches and ecodesign concept**

Position the knob in the center of the product. The power cord requires a conduit to protect it from the insulation (PUF) for serviceability. The product engineer observed that there is a potential to reduce PUF consumption if we redesign the concept sketches and also move the knob position toward the right end of the product to reduce the length of the power cord and reduce the length of the conduit pipe associated with it. The industrial designer then modified the concept sketches with a surface transition and moved the knob position towards the right end, as shown in concept 'b,' with a Length To Diameter Ratio (L/D) of 1.7. This ratio transition also results in material savings of the outer plastic jacket and packaging material. In this concept 'b,' the overall material required, component geometry, and packaging design length are redesigned with sustainability in mind without affecting the product performance and quality. Table 1 shows the ED-LCA carried out on these two concepts as per Equation 1. This ED-LCA outcome will help designers and engineers to make a quick sustainability decision and move forward with product development. From the table, it is evident that there is 11.76% decrease in the emissions in concept 'b'.

While collaborating with the product use phase, the water heater should consume less energy, but in practical terms, it is used to heat the water, and it does consume energy all the time whenever it is in the ON mode. At the same time, developing technological solutions for these, such as increasing insulation to avoid standby losses, results in increasing the product diameter. This will result in more material consumption and have an impact on sustainability. Also, the technological solutions resulted in additional costs to the product, impacting the economic aspect of sustainability.

**Table 1. Comparison of GHG emissions for concepts' a 'and 'b'**

| **Concept** | **Concept 'a' (L/D=1.8)** | | | **9.536** |
|---|---|---|---|---|
| | **Material** | **Weight** | **Emission factor** | **Total Emission** |
| **Components** | | **Kg** | **kg $CO_2$e/kg** | **kg $CO_2$e** |
| Front Cover | ABS | 0.874 | 3.125 | 2.733 |
| Rear Cover | ABS | 0.907 | 3.125 | 2.834 |
| Conduit Pipe | PE | 0.0053 | 2.00 | 0.011 |
| Power cord | Copper | 0.4 | 3.00 | 1.200 |
| Carton Box | Corrugated Fiber Board | 1.5 | 0.6 | 0.9 |
| Insulation | PUF | 0.744 | 2.5 | 1.86 |
| **Concept** | **Concept 'b' (L/D=1.7)** | | | **8.414** |
| | **Material** | **Weight** | **Emission factor** | **Total Emission** |
| **Components** | | **Kg** | **kg $CO_2$e/kg** | **kg $CO_2$e** |
| Front Cover | ABS | 0.827 | 3.125 | 2.586 |
| Rear Cover | ABS | 0.852 | 3.125 | 2.662 |
| Conduit Pipe | PE | 0.0008 | 2.00 | 0.002 |
| Power cord | Copper | 0.25 | 3.00 | 0.750 |
| Carton Box | Corrugated Fiber Board | 1.35 | 0.6 | 0.81 |
| Insulation | PUF | 0.642 | 2.5 | 1.605 |

The industrial designer resolved this problem by studying the behavior patterns of users. Generally, when the water heater is turned ON, the thermostat operates after the required set temperature is reached and cuts off the power supply to the heating element. After the cooling time, the temperature drops, and again the thermostat operates to turn on the heating element. This cycle continues all the time to maintain the required water temperature inside the tank. There was a gap to include the end user through design. An industrial designer suggested adding a temperature indicator on the water heater, as shown in Figure 6.

The user will always come to know the temperature inside the tank and take a call whether the water heater is needed to turn ON, and if it requires, until what temperature rise so that the required temperature is achieved. Thus, the temperature indicator will guide the user whether it is necessary to heat the water again in the tank. This way, energy consumption during the product use phase will be reduced or minimized.

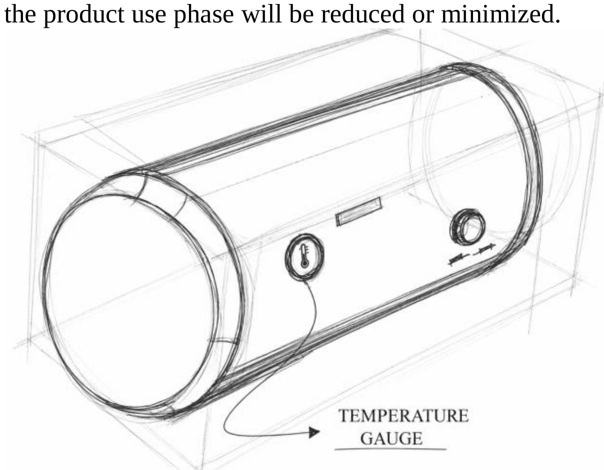


**Fig. 6 Water heater with temperature dial gauge**

In this way, it will help achieve improvement in product sustainability results through concept sketches and ecodesign concepts with better collaboration between the designer and the engineer.

## 5. Discussion

The literature review demonstrates that core industrial designers play a significant operational role in ecodesign, particularly during the conceptual stages of product development. Hence, collaboration between an industrial designer and a product engineer is crucial to radically reduce adverse environmental impact prior to production release by evaluating concept sketches (industrial designer) or concept designs (product engineer). This collaboration can be fast-tracked with AI-assistive generative design options with sketching as input for industrial designers. LCA done at the ecodesign concept level in R&D has a feedback loop to industrial designers (marketing) at the ideation level. This means negating the adverse environmental impact as early as designing the actual concepts and at the ideation stage itself. This collaboration offers industrial designers a much broader aspect of ecodesign, which the product engineer carried out.

Authors in this study have integrated the ecodesign, LCA, and ISO 14006:2020 framework for a better collaboration between the industrial designer (marketing) and the product engineer (R&D) to evaluate environmental impact at the conceptual stage for New Product Development (NPD). In this study, the authors also proposed a methodology for product redesign and product improvement for better collaboration between the industrial designer and the product engineer with the ISO 14006:2020 framework for existing products. Along with these methodologies, the ecodesign guidelines were developed by authors to arrive at environmentally friendly concepts, especially for the redesign or improvement of products. Authors also suggested that the use of the ED-LCA approach will help reach the environmental consensus between the marketing and R&D departments, as this ED-LCA is carried out during the ideation or conceptual stage of product development, and may help to bring eco products faster to market. Authors in this study presented a case study that shows there is a way forward to decrease emissions by modifying the concept sketches and the contribution of the industrial designer to the product sustainability.

Review of industrial designer concept sketch goes beyond the scope of this study, though authors listed Eco sketch [9], Biomimicry Sketch Analysis (BSA) [11], Stylistic Design Engineering (SDE) [10], Collaborative Sketching (C-Sketch) [13], mX-Sketch [14], generative designs, etc., to name a few. The real scope of concept sketches of an industrial designer is huge, and this study does not cover what is beyond the scope.

## 6. Conclusion and Future Work

As the Ecodesign and LCA integration with the ISO framework by the industrial designer and product engineer at the conceptual stage is crucial to negate the adverse environmental impact, the authors have developed a methodology for this integration of Ecodesign and LCA with the ISO framework. This will help industrial designers to contribute more to the ecodesign at the concept sketch level and negate the adverse environmental impacts of the product to be designed. Ecodesign and LCA go hand in hand, as the feedback from LCA acts as a crucial support to design products with minimum adverse environmental impact.

This collaboration approach suggested in this study will help benign designers to blend sustainability into the products they design. More detailed research is needed in the industrial design area, where the concept sketches are directly linked to environmental sustainability with AI-assisted generative design options, digital twins, and virtual reality, etc., so that the feedback from these concept sketches can be modified by the designer to know the environmental impact. There needs to be a tool or technique that assesses the ecodesign at the concept sketch level in industrial design.

Industrial designers contribute to ecodesign through material-form exploration, user-centered insights, and connecting market needs to technology. However, there always exists a misalignment between the industrial designer workflow, resulting in partial adoption in real-world practices. Authors in this study have put forward a methodology including a workflow to address this concern using the LCA approach, Ecodesign product life cycle phases, and the ISO framework. Authors have also tried to bridge the communication and information flow gap between the industrial designer and the product engineer through a proposed methodology for ecodesign, LCA approach with the ISO 14006:2020 framework. As part of future work, there will be a need to quantify and link the design decisions made by industrial designers to measurable reductions in environmental impact, with a rapid feedback mechanism between the industrial designer and product engineer to evolve ecodesign to address environmental issues.

## Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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