research
ISSN 2386-5414
e-ISSN: 2340-8391

Review | Revisión

Ecodesign as an applicable method to the didactics of Industrial Product Design in Chile | Ecodiseño como método aplicable a la didáctica del Diseño Industrial de Productos en Chile

Marcelo Venegas-Marcel

Industrial Designer and Bachelor in Design, Universidad de Valparaíso, Chile.
Department of Design and Manufacturing, Universidad Técnica Federico Santa María. Federico Santa Maria María Avenue 6090, Viña del Mar, Chile, marcelo.venegas@usm.cl, ORCID 0000-0002-6501-1312

Received: March 31, 2023 | Accepted: May 15, 2023 | Published: June 29, 2023
https://doi.org/10.25267/P56-IDJ.2023.i3.01

Resumen:

El siguiente artículo, asume la necesidad de aproximar la metodología y conceptos generales del Ecodiseño, al ejercicio práctico del Diseño de Productos. Esto, a la luz de las directrices dadas por la adaptación de ciertas etapas derivadas del Análisis de Ciclo de Vida; así como, de la identificación de oportunidades que se abren a partir de la interpretación del escenario país, ante la perentoria implementación de las distintas normativas y requerimientos que tienen por objeto la mejora ambiental.

Se propone, un modelo procedimental aplicable a la Enseñanza universitaria del Diseño Industrial en Chile, así como también, al desarrollo de la praxis disciplinar de nivel profesional y con especial enfoque, a la ejecutada en las Pequeñas y Medianas Empresas. Sistematizando de este modo, aspectos decisionales para la planificación de productos con enfoque Sostenible y en sintonía con la institucionalidad ambiental vigente.

Los resultados obtenidos, evidencian una respuesta ágil en la resolución de casos dirigidos a la optimización del Diseño. Considerándose para tal efecto, el lineamiento dado por el levantamiento de ciertos indicadores ambientales y su traspaso a estrategias de Ecodiseño, como posibles instancias de mejora. Por lo que las soluciones propuestas, consideraron principalmente criterios de reducción y reciclabilidad de materiales, optimización y desarmabilidad eficiente de partes y componentes, así como, la extensión de la vida útil del producto. Traduciéndose estos últimos factores, en prestaciones relevantes para el usuario, por constituirse en una cercana instancia comunicativa, para la comprensión y promoción de los distintos principios que sustentan las buenas prácticas medioambientales.

Palabras clave: Diseño Industrial; Educación en Diseño; Ecodiseño; Indicador ambiental; Análisis de Ciclo de Vida; Metodología

Abstract

The following article assumes the need to approximate the methodology and general concepts of Ecodesign to the practical exercise of Product Design. This, considering the guidelines given by the adaptation of certain stages derived from the Life Cycle Analysis; as well as the identification of opportunities that are opened from the interpretation of the country scenario, given the peremptory implementation of the different regulations and requirements that have the objective of environmental improvement.

It is proposed to establish a procedural model applicable to the University Teaching of Industrial Design in Chile, as well as the development of disciplinary praxis at a professional level and with particular focus, on the one executed in Small and Medium Enterprises. Systematizing in this way, decisional aspects for the planning of products with a sustainable approach and in tune with the current environmental institutional framework.

The results obtained show an agile response in the resolution of cases aimed at design optimization. Considering for this purpose, the guidelines given by collecting data of certain environmental indicators and their transfer to Ecodesign strategies, as possible instances of improvement. Therefore, the proposed solutions mainly considered criteria for the reduction and recyclability of materials, optimization and efficient disassembly of parts and components, as well as the extension of the useful life of the product. Translating these factors, into relevant benefits for the user, for constituting a close communicative instance, for the understanding and promotion of the different principles that support good environmental practices.

Keywords: Industrial Design; Design Education; Ecodesign; Environmental Indicator; Life Cycle Analysis; Methodology

Introduction

The current global economic system is primarily based on the "buy-use-throw away" cycle (MacArthur, F.E, 2015). The concept of disposability has been socially established as the ultimate expression of consumption – and in its extreme position, the consumerism – contributing to the consolidation of the Linear Economy (Piñero, 2004; Murdock, 2006). While this has enabled unprecedented industrial growth and development, it has also been accompanied by the indiscriminate use of large amounts of raw materials and low-cost energy. This principle is considered the guiding principle of the extractivist paradigm, which has been successful in its implementation but has faced considerable criticism for its negative environmental impact and the numerous social costs associated with it (Sariati,2017; Acosta,2016; Schaffartzik et al.,2014; Krausmann et al., 2011).

This context has prompted various actors to take action to change the status quo. Sustainable Design (SD) emerges as an alternative design strategy, promising greater social commitment by emphasizing productive innovation for development while assuming serious responsibilities for environmental and collective well-being (Corsini and Moultrie 2021). Ecodesign, as referred to in ISO 14006 (2011, 2) presents itself as the methodological response to environmental management in the design and development of products. It involves a more vigorous and proactive participation in the life cycle of production, optimizing energy and material resources and consistently protecting various ecosystems (Rousseaux et al. 2017; Brambila-Macias and Sakao 2021). Currently, it is one of the main methodologies used in highly industrialized countries to prevent waste generation, transforming environmental regulations into efficient and effective actions to ensure compliance while benefiting companies directly. Thus, the environmental profitability achieved can be directly translated into cost reduction, making it a real contribution to competitiveness (García et al. 2020). In this sense, in line with the concept of environmental efficiency, life cycle assessment (LCA) of material and energy flows in a product-process emerges as the primary tool for achieving environmental optimization throughout the value chain (company, suppliers, distributors and users), and its planning for effective SD.

The Chilean environmental institutions have taken significant steps towards environmental sustainability and the effective implementation of the concept of Ecodesign. Initiatives such as the enactments of the Extended Producer Responsibility (EPR) law (Law N° 20.920, 2016) aim to establish a framework policy for waste management and the extended responsibility of producers. This positions the country within a circular economic logic that aims to guide the cycle between producers, the base collection system, and users towards closure (Moraga et al., 2019; Wastling et al., 2018). However, its ongoing implementation has revealed complexities and raised concerns in various sectors. These range from institutional inefficiencies in setting recyclability targets to the difficulties faced by companies in accessing easily applicable and affordable Ecodesign instruments considering their resources. This has slowed down industrial environmental management or discouraged numerous investments in infrastructure necessary for the implementation of different regulations (Navech,2020; Sánchez,2021).

Chilean environmental institutions have decided to take important steps in terms of environmental sustainability, as well as in the possibilities of effective implementation of the Ecodesign concept. Initiatives such as the promulgation of the Extended Producer Responsibility, law EPR (Law N° 20.920, 2016), which intends in its content, the establishment of a framework policy for waste management and extended responsibility that may correspond to the producer. Undoubtedly, this positions the country in a circular economic logic, tending to be able to finally guide, towards a closure of the existing cycle between the one who produces, the base collection system and obviously the user (Moraga et al., 2019; Wastling et al., 2018). However, its implementation still under development has revealed complexities and has generated concern in the different sectors involved. From the declared institutional inefficiencies to set recyclability goal, to the difficulty – assumed from the enterprises – to access Ecodesign instruments of simple application and an affordable cost considering their resources. Therefore, slowing down industrial environmental management, or else discouraging numerous investments in infrastructure that will finally enable the implementation of different regulations (Navech,2020; Sánchez,2021).

Given this context, the prospects for environmental sustainability, Ecodesign, and its presence in higher education are promising compared to the rest of Latin America (Mac-Lean et al. 2020). Therefore, the role of Design education in universities in our country is particularly relevant if we decide to continue advancing policies aimed at good environmental practices and their successful implementation. It is imperative to create academic spaces to promote the development of simple and effective methods that lead to formative praxis of the SD concept (Perpignan et al., 2020) and its essential transfer to the national productive sector.

Considering this situation, it is necessary to acknowledge that although there is abundant global experience regarding Ecodesign methodologies and procedures applied to products (IHOBE, 2000; Wimmer and Züst, 2001; Gertsakis, 2001; Wenzel and Alting, 1999), they still do not seem to be agile enough to facilitate their implementation in design terms. This circumstance should be considered to propose relevant improvements or at least be studied to determine how to promote regulated application in the business sector (Manzano, 2022). This is a significant point of interest that is highly relevant to the present work. Accordingly, the general purpose of this work is to advance the development of a simplified application instrument for product development, particularly in the context of SD education. This contribution is understood as a preliminary step towards the gradual positioning of Ecodesign as a potential tool that can be implemented in the professional and national productive sectors.

Based on this context, the following procedural objectives are proposed to support this work: a) Define a procedure for identifying and characterizing a product to be improved, considering environmental information mainly derived from LCA work according to the general considerations of ISO14.040 (2006). b) Develop a diagnostic evaluation for the product to be optimized, determining possible scenarios for successive environmental improvements. c) Propose improvement strategies based on certain environmental indicators, in line with current regulatory requirements. This will establish guidelines for continuous optimization that can be applied to each product and/or its development process. d) Explore design solutions as trial applications of the proposed procedure, with an initial focus on those that consider the end-of-life stage of the product, ELP (Miranda de Souza and Borsato, 2016; Ma et al., 2018).

Methodology

The proposed methodological framework consists of two main phases for implementing a procedural model (Figure 1). These phases (A and B) initially establish a domain based on the evaluation and analysis of the product to be optimized according to the given assignment, considering the general stages of the balance method proposed by Zeng et al (2017). Subsequently, in the following phase, strategies and proposals are defined to formulate a new and improved Design that minimizes environmentally negative externalities. This requires a progressive application that necessarily involves the continuous evaluation and improvement of the executed design response, aiming to achieve a virtuous cycle of environmental quality integrated into the Product Design work (Rodrigues et al., 2017; Brones et al., 2017).

The detailed subphases for the proposed procedural model and their respective definitions are presented below:

Phase A. Evaluation

a.1. Recognition and balance. This stage allows establishing a characterization of the product by generating a set of data, aiming to conclude with a sort of synthetized inventory. The general structure initially considers all the identifying data, such as project type,

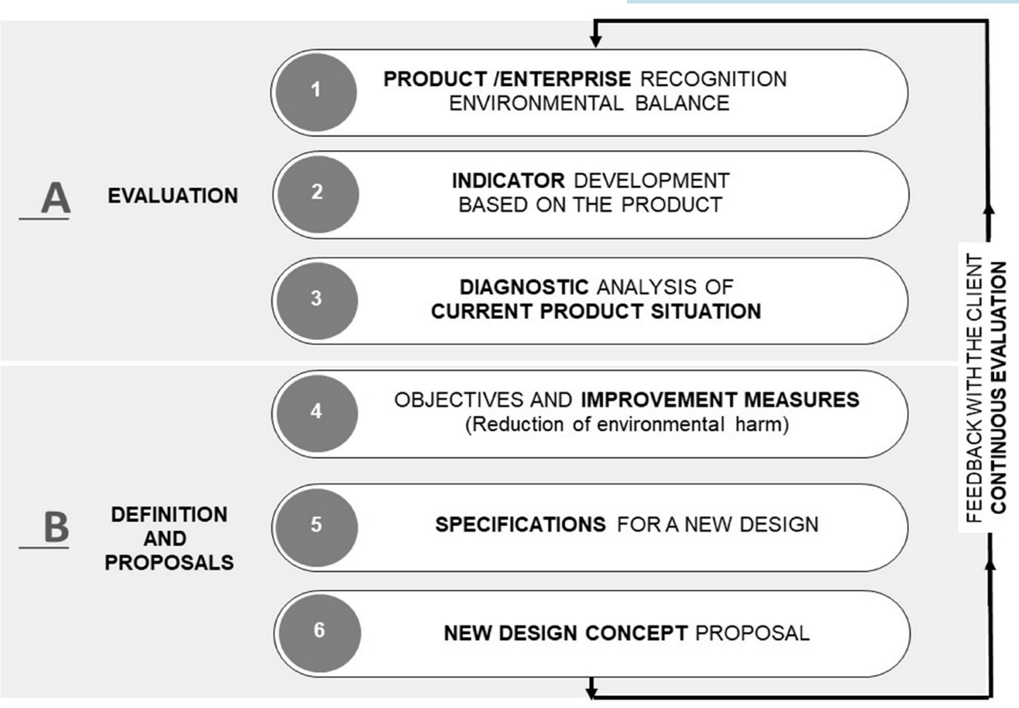


Figure 1. Phases and subphases for the proposed methodological framework.Source: Source: Own elaboration, 2022.

client company, general descriptions of the product under evaluation, responsibilities, and project progress status. In the second part, the characterization of the product is established by a general breakdown of the unit into subunits and the weighing process in grams for each of them, along with the total weight of the system in question. This constitutes a significant collection of data that forms the basis of a simplified LCA process, which is ultimately the fundamental basis of the presented model.

a.2. Indicator Development. An evaluation of the product is carried out to quantify its environmental performance. For this purpose, the development of four (4) main indicators is estimated, derived from all the information gathered in the previous recognition and balance. These indicators are directly related to the EOL and are selected based on their relevance to the environmental optimization of the product. Each indicator aims to describe the level of adjustment of a specific system, subsystem, or part of a product (SSP) based on these indices. In general, lower adjustment values indicate closer proximity to the ideal state. Therefore, higher adjustment levels describe more critical issues that require more consideration from the designer to establish optimization strategies. Consequently, these indicators become a practical guide to obtaining an overall assessment of the product, resulting in a diagnostic scenario regarding its current state, from which potential improvements can be derived (de Aguiar et al., 2017). The following are the suggested indicators for the process:

- Indicator N°1, is the Environmental Impact of the Raw Material, and requires a general characterization of the product. The aim is to assess the origin of the material, its method of extraction, the possibilities of recyclability, and the hazardous nature of the material type that constitutes the product under evaluation.

- Indicator N°2, estimates an evaluation of the environmental impact regarding energy consumption associated with the use of the product being evaluated, its relationship with power, and the variable of time in terms of usage for a specific period.

- Indicator N° 3, is defined as the functional evaluation of the product. This indicator establishes the direct applicability of the interface's performance and the user's assessment in terms of perceived efficient actions. Special emphasis is placed on functions related to the product's environmental management, such as EOL end-of-life considerations, disassembly, or durability, among others.

- Indicator N°4, establishes the evaluation of recoverability, considering the weighting of the number of present components, the number of materials, and the feasible joining systems identifiable in the overall product system.

a.3. Diagnostic analysis of the current Product Situation. This stage establishes the relationship between the collected indicators and the expected requirements in ideal terms. This analysis provides a diagnosis of the current state of the evaluated product, considering environmental requirements, and identifies areas for improvement. The principles and rules for this analysis are derived from a study proposed by the University of Delft by Brezet and Van Hemel (1997), The Netherlands, which suggests eight (8) Design strategies organized in the Life-Cycle Design Strategy (LiDS) Wheel. This application serves as a parameter for measuring relevant factors in ecological terms.

Phase B. Definition and Proposals

b.1. Objectives and Improvement Measures of a Product. The result of combining Eco-design strategies with the indicators identified in the preliminary evaluations is processed as a product diagnosis. This scenario can be represented schematically by applying a radial graph, which is essentially similar to the one developed by Brezet and Van hemel (LiDS Wheel). It synthesizes certain environmental issues into eight hierarchically ranked Eco-design strategies on a scale of one to ten. By recognizing each of the obtained averages, it interprets different areas for improvement that should be addressed to advance in environmental optimization. Thus, the preliminary formulation of certain proposals begins, which could potentially align with the needs expressed by the client and be acknowledged as valid constraints associated with the project. In line with the opportunities identified during the product evaluation, this would prioritize the proposed ideas based on their immediate implementation feasibility and help to visualize future areas for continuous improvement processes (Iuga et al, 2017; Brones et al., 2017).

b.2. Specifications for a New Design. The weaknesses identified during the analysis of the product serve as a starting point for developing new design alternatives that overcome these deficiencies. However, these alternatives should align with specific Product Design Specifications (PDS), which ultimately express the feasibility of implementation and the contextual conditions required for effectiveness. In this regard, aspects related to the product's functionality and its implications for environmental optimization, as well as specifications related to technical factors of manufacturing/assembly that contribute to minimizing environmental externalities, and regulatory requirements mandated by institutions become the basis for defining and prioritizing certain criteria. These criteria, established within the PDS, facilitate the formulation of specific judgment elements that accompany the selection process of conceptual proposals and their subsequent development at the detailed design level.

The proposed PDS enable the formulation of certain criteria, which are assigned a value expressed as a percentage. Each criteria gains a hierarchy or weight, indicating its ideal importance in relation to the product system.

b.3. Proposal for a New Design Concept. The evaluation stage progresses by assessing each of the best-developed conceptual design proposals. Each proposal to be evaluated – in accordance with the predefined criteria – is assigned a final weighting. To do this, the following steps are taken: a) each established criteria for the project is measured by assigning a score using relative scales based on the design team's needs or preferences (e.g.,from 1 to 7 or from 1 to 10); the weighting is quantified by multiplying the percentage value by the score assigned to each criterion of the conceptual proposal (% Value x Score = Weighting); finally, the total sum of all the weightings of the evaluated criteria determines a score for each conceptual design alternative. The option with the highest score is prioritized as a valid alternative to be further developed at the detailed Design level (Ulrich and Eppinger, 2009).

Results

A. Evaluation phase

The previously defined procedure was subject to testing and application in the work carried out by undergraduate courses in Industrial Design at the university level. Specifically, it was implemented in the Ecological Design workshop, corresponding to the seventh semester of the bachelor's degree program in Manufacturing and Industrial Design Engineering at the Universidad Técnica Federico Santa María, Viña del Mar campus, Chile. Therefore, this research is considered a preliminary instance that is feasible to be verified and corrected, thus allowing for potential scalability to other cases and contexts that aim to incorporate SD.

The results were presented as summarized and organized information according to the developed phase. Starting the process with the collection of necessary information for evaluation (phase a1), it involved the creation of a concise data matrix that allowed recording the balance of materials and components for further analysis. The study focused on a specific case where the main objective was to assess its environmental status and ultimately progress in its improvement. This was conducted on a low-complexity children wheeled product manufactured by Roda Corp. Spa., a Chilean brand. (Table 1)º

Table 1. Data Sheet a.1. Product Recognition and Balance. Source: Own elaboration, 2022.

roda	**Product characterization matrix** **Sheet: A1**	Review status: preview version

Objetive and Scope of product evaluation (Client brief): Progress in product environmental improvement based on initial diagnosis

PRODUCT: RODA Classic learning bike		RESPONSIBLESS:	
	Functional description: Wooden bike for preschool motor learning stage	In charge: Project manager	Department: Design and environment
		Management m/a: Professional in charge	
Product family: Yes (x) No ( )		Design and development	
Typology Name: RODA learning bike		Professional in charge	

	Component	Number	Material	Weight(grs)	Origin	Source Mat.
Frame subsystem	Body	2	Plywood	1000	Chile	Virgin
Direction subsystem	Fork	1	Plywood	400	Chile	Virgin
	Handlebar	1	Plywood	200	Chile	Virgin
	Grips	2	Colored elastomer	200	China	Virgin
	Pivot axis	1	Common metal steel	400	China	Recycled
Wheels subsystem	Rim	2	Polymer	900	China	Virgin
	Tire	2	Elastomer/Rubber	580	China	Recycled
	Cogsets	2	Metal stainless steel	100	China	Virgin
Seat subsystem	Lift Support	1	Plywood	250	Chile	Virgin
	Support Structure	1	Plywood	200	Chile	Virgin
	Cushion/Saddle	1	Polymer/ Synthetic textile	100	China	Virgin
Junctions subsystem	Adjustment bolts	12	Metal stainless steel	150	China	Virgin
	Adhesive	1	Epoxy	20	Chile	Virgin
			TOTAL	**4500**		

Based on the data obtained in sheet a1, the development of indicators was carried out, starting with those related to the environmental aspect and their impact resulting from the use of the previously identified raw materials in the product (sheet a2.1). For this purpose, the method proposed by Venegas et al. (2019) was adapted, which, through the breakdown of the total unit (product) into its different material subsystems, allowed for obtaining the percentage values relative to the weight (in grams) of each typology comprising the system. Therefore, the collected indicators, their weighting, and the criteria considered for this purpose can be observed in Table 2.

The second indicator measured the environmental impact in relation to energy consumption. To do this, the product was linked to its nominal power expressed in kilowatts (kW), the effective hours of use in an annual period, the estimated lifespan of the product, and finally the calculation to obtain the amount of energy consumed per hour (kWh) over a year, multiplied by the years of use or lifespan (kWh/year * years of use).

In the case of the specific product being examined, which is a children's wheeled item activated mainly by human-powered mechanical traction or propulsion, the second indicator could not be calculated. Therefore, according to the criteria established for obtaining the indicator, the highest score is applied. This information was recorded in Table 3, which displays the result and the criteria applied for this purpose.

The indicator number 3, which assesses the functional performance of the product, was carried out by examining the various features that make up the product system and organizing them into subgroups. Each function to be evaluated was assigned a numerical scale to provide an objective reference for rating. In this regard, a hierarchical value or score (Sc) was created to estimate the degree of importance of each function within the system, using

Table 2. Sheet a.2.1. Environmental Impact and Raw Materials. Source: Own elaboration, 2022.

roda	Environmental impact matrix Sheet: A2.1	Review status: preview version	

Product Charaterization			Material				Recyclability		Hazardousness		
Material	Weight(grs)	% Total Weight	Origin	Score	Source Mat.	Score	Recyclable	% recyclability	Hazard	Code DS 148	% hazardousness
Plywood	2.050	45,6	National	5	Non-renewable	1	no	14,4	no		0
Colored elastomer	200	4,4	International	1	Non-renewable	1	no		no		
Common metal steel	400	8,9	International	1	Recycled	10	si		no		
Polymer	900	20,0	International	1	Non-renewable	1	no		no		
Elastomer/Rubber	580	12,9	International	1	Non-renewable	1	no		no		
Metal stainless steel	250	5,6	International	1	Non-renewable	1	si		no		
Polymer/ Synthetic text	100	2,2	International	1	Non-renewable	1	no		no		
Epoxic	20	0,4	International	1	Non-renewable	1	LiDs score	1,4	LiDs score	1	
Total Weight	4.500	100,0	subtotal	1,5		2,1					
			LiDs score	1,8							

Material Criteria (Average of 2 atributes)		
Material Origin Criteria		
LOW	10 pt	If the product consumes local/regional mat.
MEDIUM	5 pts	If the product consumes national mat.
HIGH	1 pt	If the product consumes international mat.
Source Material Criteria		
LOW	10 pt	If the product contains recycled raw mat.
MEDIUM	5 pts	If the product contains renewable raw mat.
HIGH	1 pt	If the product contains non-renewable raw mat.
Recyclability Criteria		
HIGH	10 pt	80 to 100% recyclable mat.
MEDIUM	5 pts	40 to 79 %
LOW	1 pt	0 to 39 %
Hazardousness criteria		
LOW	10 pt	80 to 100% hazard mat.
MEDIUM	5 pts	40 to 79 %
HIGH	1 pt	0 to 39 %

a nominal scale from one (1) to five (5). A score of 1 represents the lowest level of importance, while a score of 5 indicates the highest level of interest for that function within the product system.

Bases on the above, the evaluation proceeded by specifically assessing each function within the system, using the predetermined rating scale. The voting (Vot.) was established on a scale ranging from very poorly resolved (1) to optimally fulfilled and resolved in the product, i.e., very well resolved (5).

Subsequently, a quantitative approach was taken to obtain evaluations in percentage points , which were recognized as functional indicators. For this purpose, the ideal sum (∑i) of each subsystem was calculated, derived from the sum of all squared Scores (Sc2); Similarly, the actual voting (A.V.) was shown in column 5, which combines the actual sum (∑a) of all products given the Score established for each function of the subsystem and its corresponding voting (Sc. x Vot.). Both sums are useful for calculating the percentage (%) of compliance for each subsystem and function by applying a proportional operation. This information was recorded in column 6, representing the feasible level of conformity within the functional features of the entire subsystem.

In addition, the overall functional compliance of the product (in %) can also be noted by comparing the ideal total sum of the product (∑ti) with the actual total sum (∑at).

Finally, functions that were evaluated and directly related to certain environmental criteria to be considered in the project were highlighted in yellow. For this purpose, it was estimated that associating 100% functional performance with a LiDS score scale of 1 to 10, where one point is equivalent to ten percentage points (1=10%), would be appropriate. All of the above, along with the collected indicators were recorder in Table 4.

The fourth indicator involved an analysis of the product's disassembly and its ease of accessing components for efficient recovery through recycling. The analysis assessed the EOL of the product, with a specific focus on Design for Disassembly (DfD). DfD refers to the current feasibility within the product system to prevent the destructive separation of its components, aiming to minimize waste at the end of its lifecycle and create opportunities for future recovery (Abuzied et al., 2020; Chiu and Okudan, 2010).

A detailed analysis was conducted, considering various indicators and the resulting LiDS score was recorded in Table 5, along with the corresponding weighting.

Completing the initial phase of Product Evaluation, a diagnostic analysis was carried out to assess the current environmental performance of the product. This involved establishing a correlation between the eight Eco-design strategies and the average of the indicators that align with these strategies. As a result, the LiDS score was obtained, providing a basis for identifying potential areas of environmental improvement for the product in question. The data obtained from this analysis can be seen in Table 6.

Table 3. Sheet a.2.2. Environmental Impact and Energy Consumption. Fuente: Source: Own elaboration, 2022.

roda	Environmental Impact Matrix: Energy Consumption Sheet: A2.2			
Product	Power kW	Hr/year	Lifespan estimation (years)	Energy consumption during product use (kW x Hr/year x years of use)
n/a				

Energy Usage Magnitude Criteria		
Evaluation	LiDs Score	Condition
LOW	10 pts	If the product consumes less than 100 kWh
MEDIUM	5 pts	If the product consumes less than 100-1000 kWh
HIGH	1 pt	If the product consumes more than 1000 kWh

Table 4. Sheet a.2.3. Product Functional Evaluation Matrix. Source:

roda	Product functional evaluation Matrix Sheet: A2.3					
FUNCTIONS	SCORE	VOTING	Ideal Score (Sc^2)	Actual Vot. (Sc x Vot)		
ROLL FOR MOVEMENT			Σi=73	Σa=43	subsyst = 59%	
Pull f/m	4	2	16	8	50	
Balance	4	3	16	12	75	
Stop	4	2	16	8	50	
Roll	5	3	25	15	60	
STEER			Σi=43	Σa=24	subsyst = 56%	
Maneuver f/m	3	1	9	3	33	
Turn f/m	3	2	9	6	67	
Steer	5	3	25	15	60	
ASSEMBLE/DISSASSEMBLE			Σi=65	Σa=44	subsyst = 68%	
Hold f/a-d	2	1	4	2	50	
Connect f/a	4	2	16	8	50	
Secure Assembly	3	2	9	6	67	
Adjust f/a	4	3	16	12	75	
Disassemble f/transportation	4	3	16	12	75	** Lids Score
Manipulate f/a-d	2	2	4	4	100	
RESIST STRESS			Σi=57	Σa=39	subsyst = 68%	
Fix components to r/s	4	3	16	12	75	
Distribute load to r/s	4	3	16	12	75	
Resist bending	4	3	16	12	75	
Resist torsion	3	1	9	3	33	
MANAGE EOL			Σi=67	Σa=25	subsyst= 37%	
Disassemble f/disposal	3	2	9	6	67	** Lids Score
Vary usage	5	1	25	5	20	** Lids Score
Extend usability	5	2	25	10	40	** Lids Score
Discard	2	1	4	2	50	
Recycle	2	1	4	2	50	
			Σti=305	Σta=175	Total product. =57%	

B. Definition and Proposals phase

Assuming the eight strategies of Ecodesign as a framework for addressing uncertainties that environmentally conscious Design should consider, the utilization of this references was determined to be a valuable input for generating new Design proposals (Liu and Zhao, 2020; Rungyuttapakorn and Wongwatcharapaiboon, 2020; Zhang and Li, 2019; Diago et al., 2019; Singh and Sarkar, 2019; Carey et al., 2019).

This scenario was schematically represented, using a radial graph, similar to the LiDS Wheel developed by Brezet y Van Hemel with the eight Ecodesign strategies hierarchically ranked on a scale from a one to ten. Additionally, a summary matrix was created, documenting the obtained LiDS score and the prioritized improvements proposals that have been chosen for implementation.

Based on the results obtained in matrix B1, the next step, known as the PDS, is established to guide the progression of

Table 5. Sheet a.2.4. Product Recoverability Evaluation. Source: Own elaboration, 2022.

roda	Recoverability Evaluation Matrix Sheet : A2.4	

	Component	Number	Material	Components number	Materials number	Joint Systen
Frame subsystem	Body	2	Plywood	13	9	mixed
Direction subsystem	Fork	1	Plywood			
	Handlebar	1	Plywood			
	Grips	2	Colored elastomer			
	Pivot axis	1	Common metal steel			
Wheels subsystem	Rim	2	Polymer			
	Tire	2	Elastomer/Rubber			
	Cogsets	2	Metal stainless steel			
Seat subsystem	Lift Support	1	Plywood			
	Support structure	1	Plywood			
	Cushion/Saddle	1	Polymer/ Synthetic textile			
Junctions subsystem	Adjustment Bolts	12	Metal stainless steel			
	Adhesive	1	Epoxic			
			Subtotal	1	5	[illegible]
			Average	3,7		
			LiDs Score	3,7		

Recoverability Criteria (Average of 3 attributes)		
Components number		
LOW	10 pts	If the product has up to 3 pieces
MEDIUM	5 pts	If the product has up 6 to 10 pieces
HIGH	1 pt	If the product has more than 10 pieces
Materials number		
LOW	10 pts	If the product has up to 3 materials
MEDIUM	5 pts	If the product has up to 6 to 10 materials
HIGH	1 pt	If the product has more than 10 materials
Joint System		
LOW	10 pts	If the product presents transitory joint system
MEDIUM	5 pts	If the product presents mixed joint system
HIGH	1 pt	If the product presents permanent joint system

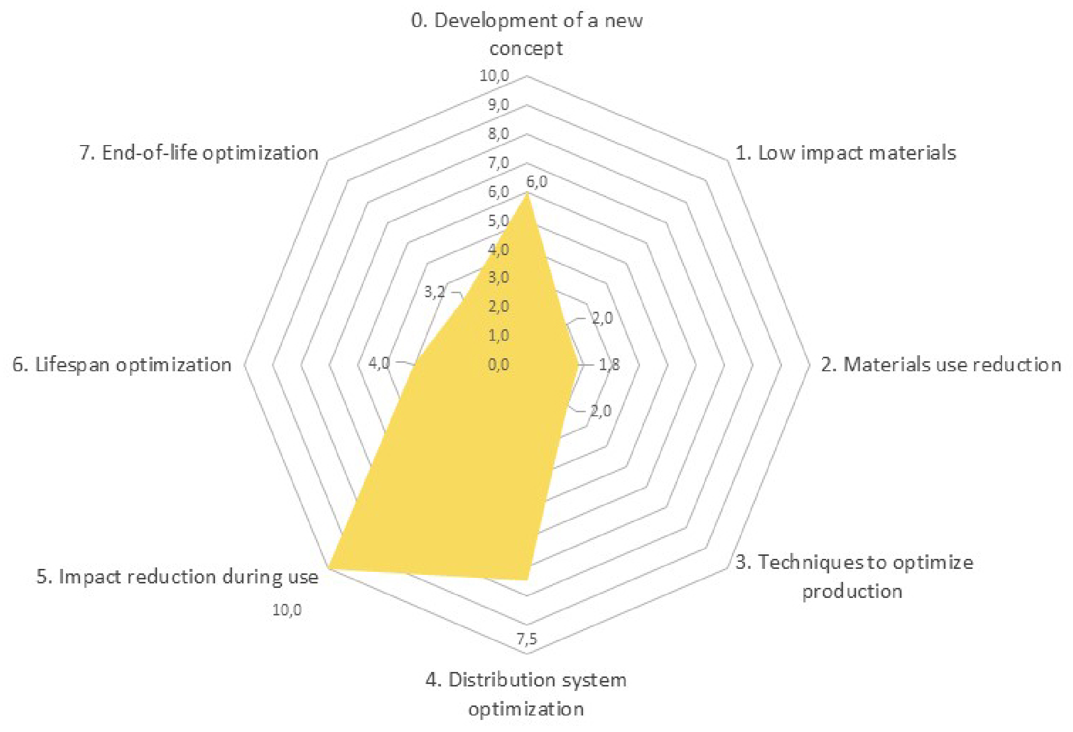
Table 6. Sheet a.3.1. Scenario Analysis for Ecodesign. Source: Own elaboration, 2022.

roda — **Scenario Analysis for Ecodesign Matrix**
Sheet : A3.1

	IND 1			IND 2	IND 3	IND 4	
ECODESIGN STRATEGIES	Material	Recyclability	Hazardousness	Use Energy	Usability	Recoverability	Average
0. Development of a new concept				10,0	2,0		6,0
1. Low impact materials	1,8	1,4	1,0			3,7	2,0
2. Materials use reduction	1,8						1,8
3. Techniques to optimize production		1,4	1,0			3,7	2,0
4. Distribution system optimization					7,5		7,5
5. Impact reduction during use				10,0			10,0
6. Lifespan optimization					4,0		4,0
7. End-of-life optimization		1,4	1,0		6,7	3,7	3,2

Table 7. Sheet b.1. Diagnosis and Ecodesign Strategies. Source: Own elaboration, 2022.

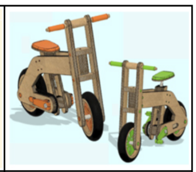
roda — **Diagnosis and Ecodesign Strategies**
Sheet : B1



Items	Lids Score	Proposal	Conclusions per Item
0. Development of a new concept	6,0		
1. Low impact materials	2,0	Prioritize materials made from recycled or renewable sources	Enhace the application of recycled wood, steel, and polymers
2. Materials use reduction	1,8	Minimize number of materials	Limit the variety of materials to a maximum in structural, mechanical, and operational systems
3. Techniques to optimize production	2,0	Simplify manufacturing processes and their relationship with designed parts	Fewer parts, fewer operations
4. Distribution system optimization	7,5		
5. Impact reduction during use	10,0		
6. Lifespan optimization	4,0	Extension of durability in use	Expansion of functions based on user age. Older age, additional functions
7. End-of-life optimization	3,2	Simplify collection for recycling	Facilitate disassembly for EOL

Table 8. Sheet b.2. Design Proposal Selection. Source: Own elaboration, 2022.

roda	**Design Proposal Selection Matrix** **Sheet: B2.**	

									
		Concept (A)		Concept (B)		Concept (C)		Concept (D)	
Selection Criteria	Value (%)	Grade	Weighting	Grade	Weighting	Grade	Weighting	Grade	Weighting
Restriction of material variety	30	5	1.5	5.5	1.65	5.5	1.65	5	1.5
Recyclability and renewability of materials	25	4	1	5	1.25	5	1.25	5	1.25
Optimization of parts and its production	15	3	0.45	5	0.75	5.8	0.87	4.5	0.675
Simplified disassembly for recycling	15	6	0.9	5.5	0.83	5.5	0.83	4.8	0.72
Extended durability through use	15	5	0.75	4	0.6	5	0.75	4	0.6
	Total points		4.6		5.1		5.4		4.7
	Selection		4		2		1		3
	¿Choose?		No		No		Yes		No

Infant Bike. Proposal and details Design.

Design: P.Castro/ E.Barahona   Design Work Team: M.Celedón/ V. Dosow/ M.Droguett/ K. Fernández- UTFSM   Professor in charge: Marcelo E. Venegas Marcel

Figure 2. Proposal and Detailed Design for the Product. Source: Adapted by the author from de Castro and Barahona, 2022.

the alternative generation and evaluation process. It is understood that the strategies with lower scores serve as the starting point for defining the criteria to be used in the selection process of those alternatives. The derived criteria for selection are as follows: a) restriction of material variety; b) recyclability and renewability of materials; c) optimization of parts and production; d) simplified disassembly for recycling; e) extended durability through use.

The process of alternative selection and the corresponding weighting based on these criteria can be observed in Table 8.

For the specific product under consideration, a concept that aligns with the established criteria and weights was selected. This concept was further developed into design solutions that address usability and detailed aspects, as depicted in Figure 2.

The developed concept is ready to be prototyped and can continue to be evaluated and optimized with a perspective of continuous improvement. This includes integrating new requirements from the client for environmental optimization and considering any new regulations established by environmental institutions.

Conclusion

-The proposed method allowed the identification and characterization of a product, considering the future reduction of environmental externalities generated by each of its components, the composition of its materials and its production characteristics. This was achieved through the registration of an abbreviated environmental assessment, based on the selection of the most relevant and priority aspects for this purpose. Thus, it presents a schematic collection of information, organized with key data that constitute and define the physical material system under analysis.

In this way, this instrument would serve as a valid tool to address Product Design projects, whether viewed from the required pedagogical needs, the learning criteria in the teaching of different project workshops, or specialized subjects. Additionally, it can also be applied to projects that require an efficient resolution under productive parameters, but with an environmental perspective. Ultimately, it acts as a guide that facilitates the evaluation of potential scenarios to be considered in decision-making processes for improving manufactured products, but with a sustainable perspective.

- The procedure presented here emphasized the importance of considering objective criteria to proceed accurately with the analysis and subsequent formulation of environmental indicators associated with products. This constitutes the updated framework to be considered as the starting point for each specific case to be addressed, thereby ensuring, the necessary prior planning of an agile and efficient structure capable of responding to the various changes in regulations defined by environmental institutions.

-The initial diagnosis directly influences the prioritization of environmental improvement strategies applicable to the development of new Product Design proposals. These measures should guarantee not only the functional aspects derived from practical and utilitarian user needs but also the specific production requirements defined by the client. This allows for a targeted and regulated selection of the proposed improvements in project optimization. Thus, the relevance of having an objective and weighted evaluation of the various conceptual alternatives that arise during the design process undertaken by the development team is confirmed.

In this regard, the Selection matrix (b2) appears to be an efficient evaluation tool in response to the demanding requirements suggested by the different criteria considered in the search for the optimal Design solution.

- The Design solution that was implemented aligned specifically with the diagnostic overview obtained through the application of the proposed method. Although it was challenging to determine the indicator associated with recyclability due to the existing and updated recycling infrastructure in the area, it was addressed nominally considering the nature of the raw material. This confirmed that the proposed instrument is flexible in the need to test the definition of indicators, even in the presence of limited general information. This allowed the verification of the flexibility of the methodological instruments and the scalability in their application, as indicated by Favi et al., (2019), this flexibility should be reflected in both educational projects within the university setting and, in the context, related to the needs of the company.

- Likewise, it was highlighted that the Design solutions developed through the application of the instrument place special emphasis on EOL as a relevant strategy applied to the product in question. This focuses primarily on the recyclability of waste, disassembly, and the reduction of the product's volume, aiming to facilitate the collection and final management of the materials that make up the system. Therefore, it is concluded that this approach, although not the only one addressed in the project, would contribute to the future collective integration of the principles that underpin good environmental practices (Rossi et al., 2016).

- It is important to note that, for the purpose of this work, certain variables were simplified in order to align with Ecodesign strategies. This includes the environmental regulations applicable to the EOL stage of certain products (such as EPR law, prioritized products). However, despite these simplifications, it is possible to continue refining the instrument in terms of more precise quantification, even while using the LiDS wheel as a basis.

- The research conducted is potentially adaptable to the evaluation and analysis of typologies of product families. This opens up an important opportunity to further refine the obtaining of weighted indicators. It allows for a potential cross-referencing of information derived from the comparative evaluation of products developed within a company or within a specific productive sector. This facilitates the identification and subsequent resolution of various environmental bottlenecks associated within materials and/or processes (Valero et al., 2018; Brundage et al., 2018).

- The presented work represents an initial methodological trial applicable to improving products from an environmental perspective. It establishes simplified procedures, centered around the fundamental concepts of Ecodesign, that can be readily incorporated into the most common phases of the Design process. It is expected that in the near future, these tools can be gradually integrated into academic exercises within carious design workshops that choose to address the challenges of SD in their projects. Additionally, these tools can be used to prototype solutions for professional practice within companies, tailored to the specific needs of clients. By doing so, the concept of environmental continuous improvement can be embraced, advancing the notion of quality associated with sustainability.

References

Abuzied, H., Senbel, H., Awad, M., & Abbas, A. (2020). A review of advances in design for disassembly with active disassembly applications. *Engineering Science and Technology, an International Journal*, *23* (3), 618-624. https://doi.org/10.1016/j.jestch.2019.07.003

Allen, J. D., Stevenson, P. D., Mattson, C. A., & Hatch, N. W. (2019). Over-Design Versus Redesign as a Response to Future Requirements. *Journal of Mechanical Design, 141*(3). https://doi.org/10.1115/1.4042335

Brezet, H., & van Hemel, C. (1997). *Ecodesign: A promising approach to sustainable production and consumption* (1°). U.N.E.P.

Brones, F. A., Carvalho, M. M. de, & Zancul, E. de S. (2017). Reviews, action and learning on change management for ecodesign transition. *Journal of Cleaner Production 142*, 8-22. https://doi.org/10.1016/j.jclepro.2016.09.009

Brundage, M. P., Bernstein, W. Z., Hoffenson, S., Chang, Q., Nishi, H., Kliks, T., & Morris, K. C. (2018). Analyzing environmental sustainability methods for use earlier in the product lifecycle. *Journal of Cleaner Production*, *187*, 877-892. https://doi.org/10.1016/j.jclepro.2018.03.187

Carey, M., White, E. J., McMahon, M., & O'Sullivan, L. W. (2019). Using personas to exploit environmental attitudes and behaviour in sustainable product design. *Applied Ergonomics, 78,* 97-109. https://doi.org/10.1016/j.apergo.2019.02.005

Castro, P., Barahona, E., Celedón, M., Dossow, V., Droguett, M., & Fernández, K. (2022). *Diseño de Rodado de baja complejidad. Taller de Diseño Ecológico, UTFSM*. [Presentación para examinación semestral de asignatura]. Entrega Final de Taller Diseño Ecológico, Viña del Mar, Chile.

Chiu, M.-C., & Okudan, G. E. (2010). Evolution of Design for X Tools Applicable to Design Stages: A Literature Review. *Volume 6: 15th Design for Manufacturing and the Lifecycle Conference; 7th Symposium on International Design and Design Education*, 171-182. https://doi.org/10.1115/DETC2010-29091

De Aguiar, J., Oliveira, L. de, Silva, J. O. da, Bond, D., Scalice, R. K., & Becker, D. (2017). A design tool to diagnose product recyclability during product design phase. *Journal of Cleaner Production*, C(141), 219-229. https://doi.org/10.1016/j.jclepro.2016.09.074

Diago, L., Lacasa, E., Urmente, L., Millán, I., & Santolaya, J. L. (2019). Integrating Sustainability in Product Development Projects. En F. Cavas-Martínez, B. Eynard, F. J. Fernández Cañavate, D. G. Fernández-Pacheco, P. Morer, & V. Nigrelli (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing II* (pp. 13-22). Springer International Publishing. https://doi.org/10.1007/978-3-030-12346-8_2

Diehl, J. C., & Brezet, H. (2005). *Ecodesign Education: Personalized Design Knowledge Transfer.* 11. ttps://www.researchgate.net/publication/310649594_ECODESIGN_EDUCATION_PERSONALISED_DESIGN_KNOWLEDGE_TRANSFER

Duan, Y., Gao, H., Li, J., & Huang, M. (2015). Formalizing Over Design and Under Design. *International Journal of Multimedia and Ubiquitous Engineering,* 10(12), 279-288.

Favi, C., Marconi, M., & Germani, M. (2019). Teaching eco-design by using LCA analysis of company's product portfolio: The case study of an Italian manufacturing firm. *Procedia CIRP,* 80, 452-457. https://doi.org/10.1016/j.procir.2019.01.032

Gertsakis, J. (2001). Maximising Environmental Quality through EcoredesignTM. En *Sustainable Solutions* (p. 13). Routledge.

Gupta, R. K., Belkadi, F., & Bernard, A. (2017). Evaluation and management of customer feedback to include market dynamics into product development: Satisfaction Importance Evaluation (SIE) model. DS 87-4 *Proceedings of the 21st International Conference on Engineering Design (ICED 17)* Vol 4: Design Methods and Tools, Vancouver, Canada, 21-25.08.2017, 4, 327-336.

IHOBE. (2000). *Manual Práctico de Ecodiseño. Operativa de Implantación en 7 pasos* (1º). IHOBE, S.A. https://www.euskadi.eus/contenidos/documentacion/ekodiseinu7/es_def/adjuntos/PUB-2000-014-f-C-001.pdf

Iuga, A., Popa, V., & Popa, L. (2017). Industrial Product Life Cycle Stages and Lifecycle Eco-design. En V. Majstorovic & Z. Jakovljevic (Eds.), *Proceedings of 5th International Conference on Advanced Manufacturing Engineering and Technologies* (pp. 365-374). *Springer International Publishing. https://doi.org/10.1007/978-3-319-56430-2_27*

Liu, C., & Zhao, Y. (2020). The Application of Lifecycle Design Strategies in the Interaction Design. En R. S. Goonetilleke & W. Karwowski (Eds.), *Advances in Physical Ergonomics and Human Factors* (pp. 369-376). Springer International Publishing. https://doi.org/10.1007/978-3-030-20142-5_37

Ma, J., Kremer, G. E. O., & Ray, C. D. (2018). A comprehensive end-of-life strategy decision making approach to handle uncertainty in the product design stage. *Research in Engineering Design*, 29(3), 469-487. https://doi.org/10.1007/s00163-017-0277-0

Manzano, M. G. (2022). Rol del Ecodiseño *en la Industria Chilena del Plástico. Tekhné, 25(1), Article 1.*

Miranda de Souza, V., & Borsato, M. (2016). Combining Stage-GateTM model using Set-Based concurrent engineering and sustainable end-of-life principles in a product development assessment tool. *Journal of Cleaner Production, 112, 3222-3231. https://doi.org/10.1016/j.jclepro.2015.06.013*

Rodrigues, V. P., Pigosso, D. C. A., & McAloone, T. C. (2017). Measuring the implementation of ecodesign management practices: A review and consolidation of process-oriented performance indicators. *Journal of Cleaner Production,* 156, 293-309. https://doi.org/10.1016/j.jclepro.2017.04.049

Rossi, M., Germani, M., & Zamagni, A. (2016). Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies. *Journal of Cleaner Production*, 129, 361-373. https://doi.org/10.1016/j.jclepro.2016.04.051

Rungyuttapakorn, C., & Wongwatcharapaiboon, J. (2020). *Eco-Design product development for alternative dishwashing detergent*. 8-16.

Singh, P. K., & Sarkar, P. (2019). Eco-design Approaches for Developing Eco-friendly Products: A Review. En K. Shanker, R. Shankar, & R. Sindhwani (Eds.), *Advances in Industrial and Production Engineering* (pp. 185-192). Springer. https://doi.org/10.1007/978-981-13-6412-9_17

Ulrich, Karl & Eppinger, Steven. (2009). *Diseño y desarrollo de productos* (4°). Mc Graw Hill.

Valero, A., Valero, A., Calvo, G., & Ortego, A. (2018). Material bottlenecks in the future development of green technologies. *Renewable and Sustainable Energy Reviews*, 93, 178-200. https://doi.org/10.1016/j.rser.2018.05.041

Venegas, M. E., Navarro, A., & Alfaro, E. (2019). Modelo procedimental para la caracterización y valoración de residuos de aparatos eléctricos y electrónicos, RAEE. *Cuadernos Del Centro De Estudios De Diseño Y Comunicación*, 87, 285-298. https://doi.org/10.18682/cdc.vi77

Wenzel, H., & Alting, L. (1999). Danish experience with the EDIP tool for environmental design of industrial products. *EcoDesign '99: First International Symposium* On, 370-379. https://doi.org/10.1109/ECODIM.1999.747640

Wimmer, W., & Züst, R. (2001). *ECODESIGN Pilot: Product Investigation, Learning and Optimization Tool for Sustainable Product Development (1°). Springer.*

Zeng, X., Yang, C., Chiang, J. F., & Li, J. (2017). Innovating e-waste management: From macroscopic to microscopic scales. *Science of The Total Environment,* 575, 1-5. https://doi.org/10.1016/j.scitotenv.2016.09.078

Zhang, B.-Y., & Li, J. (2019). Design for Environmental Protection: Measuring the Appeal Factors of Green Product for Consumers. *Ekoloji*, 28(107), 1699-1707.

proyecta56

An industrial design journal

Funding source / Fuente de financiación

This work has not received any funding. / Este trabajo no ha recibido ninguna fuente de financiación