DESIGN FOR REVERSE LOGISTICS GUIDELINES: A LITERATURE REVIEW

DIRETRIZES DE PROJETO PARA LOGÍSTICA REVERSA: UMA REVISÃO DA LITERATURA

DIRECTRICES DE DISEÑO PARA LA LOGÍSTICA INVERSA: UNA REVISIÓN DE LA LITERATURA

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ABSTRACT

Environmental challenges related to solid waste generation and disordered consumption are becoming increasingly prominent. The Circular Economy (CE) has emerged as a strategy for generating value through effective waste management, and *Reverse Logistics* (RL) plays an important role in the transition to CE. Sustainable Design (SD) and *Design for Reverse Logistics* (DfRL) have emerged as approaches to integrating RL into product design. This research aimed to explore the context of Design Guidelines (DG) for RL under the concept of DfRL. To this end, a Systematic Literature Review (SLR) approach was used. The research covered aspects of DG, such as related Design for Excellence (DfX), product design context, relationship with RL, sustainability and the Sustainable Development Goals (SDGs). In addition, the research identified research gaps, such as the definition of the term and hierarchy around DG and the need for integration between research and technique to share design information. Potential areas were identified for DfRL and for integrating RL into the product process, promoting the transition to a more sustainable and circular production model, in line with the SDGs and the needs of future generations.

KEYWORDS

Circular Economy; Sustainable Design; Reverse Logistics; *Design for Reverse* Logistics; Design Guidelines.

RESUMO

Desafios ambientais relacionados à geração de resíduos sólidos e ao consumo desordenado ganham cada vez mais destaque. A Economia Circular (EC) surgiu como estratégia de geração de valor, por meio de uma gestão eficaz dos resíduos, e a Logística Reversa (LR) desempenha um papel importante na transição para a EC. O Design Sustentável (DS) e o Design for Reverse Logistics (DfRL) surgem como abordagens para integrar a LR ao projeto de produtos. Esta pesquisa objetivou explorar o contexto das diretrizes de projeto para LR sob o conceito de DfRL. Para isso, utilizou-se uma abordagem de Revisão Sistemática da Literatura (RSL). A pesquisa abrangeu aspectos acerca de diretrizes de projeto, como Design for Excellence (DfX) relacionados, contexto de projeto de produto, relação com a LR, a sustentabilidade e os Objetivos de Desenvolvimento Sustentável (ODS). Além disso, a pesquisa identificou lacunas de pesquisa, como a definição do termo e hierarquia acerca de diretrizes de projeto e a necessidade de integração entre pesquisa e técnica para compartilhamento de informações de projeto. Foram identificadas áreas potenciais para o DfRL e para integrar a LR ao processo do produto, promovendo a transição para um modelo de produção mais sustentável e circular, alinhado aos ODS e às necessidades das gerações futuras.

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PALAVRAS-CHAVE

Economia Circular; Design Sustentável; Logística Reversa; Design para Logística Reversa; Diretrizes de Projeto

RESUMEN

Los desafíos ambientales relacionados con la generación de residuos sólidos y el consumo desordenado están ganando cada vez más relevancia. La Economía Circular (EC) surgió como una estrategia para generar valor a través de una gestión eficaz de los residuos, y la Logística Inversa (LI) desempeña un papel importante en la transición hacia la EC. El Diseño Sostenible (DS) y el Diseño para la Logística Inversa (DfLI) emergen como enfoques para integrar la LI en el diseño de productos. Esta investigación tuvo como objetivo explorar el contexto de las directrices de diseño para la LI bajo el concepto de DfLI. Para ello, se utilizó un enfoque de Revisión Sistemática de la Literatura (RSL). La investigación abarcó aspectos sobre las directrices de diseño, como el Diseño para la Excelencia (DfX) relacionado, el contexto del diseño de productos, la relación con la LI, la sostenibilidad y los Objetivos de Desarrollo Sostenible (ODS). Además, la investigación identificó brechas en la literatura, como la definición del término y la jerarquía sobre las directrices de diseño, así como la necesidad de integración entre investigación y técnica para el intercambio de información de diseño. Se identificaron áreas potenciales para el DfLI y para integrar la LI en el proceso del producto, promoviendo la transición hacia un modelo de producción más sostenible y circular, alineado con los ODS y las necesidades de las generaciones futuras.

PALABRAS CLAVE

Economía Circular; Diseño Sostenible; Logística Inversa; Diseño para Logística Inversa; Directrices de Diseño

1. INTRODUCTION

In recent years, the world has faced significant challenges related to environmental problems associated mainly with the generation of solid waste and the disorderly consumption of natural resources. In 2010, Brazil approved the National Solid Waste Policy - PNRS (established by Law 12.305 of August 2010), which emphasizes the need to find integrated solutions to solve the problems arising from the generation of waste that can affect the quality of life of Brazilians. The PNRS presents *Reverse Logistics* (RL) as an instrument of economic and social development characterized by a set of actions, procedures and means designed to enable the collection and return of solid waste to the business sector, for reuse, in its cycle or other production cycles, or another environmentally appropriate final destination" (Brasil, 2010).

The depletion of resources is considered a problem for the economic sustainability of the current production and consumption model, which needs to be reviewed to transition to a social and productive model that does not jeopardize the survival opportunities and well-being of future generations (Manzini; Vezzoli, 2016).

The culture of unbridled and disposable consumption plays a fundamental role in the excessive generation of waste. In addition to this, it is important to address sustainable strategies that promote economic and social development while reducing negative environmental impacts.

One of these strategies is the Circular Economy (CE) a model that aims to produce value without destroying nature, but rather restoring and protecting it (Sehnem; Pereira, 2019). The CE is an environmental management policy that aims to improve the management of resources used in production chains (Su, Heshmati, & Geng, 2013), preventing the deterioration of the environment and promoting the conservation of scarce resources through effective waste management, especially solid waste management (Sehnem and Pereira, 2019). The CE model, according to the Ellen MacArthur Foundation (2017) has four technical cycles consisting of product maintenance; reuse/ redistribution - used product; product updating/ remanufacturing; and product recycling.

When dealing with these propositions concerning the process and the product from the CE, RL are seen in the encounter between the items returned in the chain and the possible activities for recovering value and the final destination of the waste (Melo *et al.*, 2022). Rogers and Tibben-Lembke (1998) defined RL as the process of efficiently planning, implementing and controlling the economic flow of raw materials, in-process inventory, finished products and information related to the point of consumption and origin, to recover value or dispose of it properly. Thus, RL plays an important role in the transition to CE, as it involves returning products, materials and packaging to the production cycle to recover value, instead of sending them directly to landfills.

Melo *et al.* (2021) also cite *Reverse Logistics* as an efficient set of resources and actions that can play an important role in promoting Sustainable Design (SD), considering DfX (*Design for X or Design for Excellence*) approaches, more specifically *Design for Reverse Logistics* (DfRL). SD is understood to be a wide range of design activities on the product system, which tend to address the issues posed by the environmental issue by linking the technically possible with the ecologically necessary, resulting in new socially and culturally appreciable proposals whose acceptance depends on a change in the culture and behaviour of consumers (Manzini; Vezzoli, 2016).

Following this logic and aiming to find applicability to the set of actions from CE, RL and DS, the most objective approaches concerning different sets of actions and products are DfX, which, according to Melo, Merino and Merino (2017), aims to design products with a focus on optimized characteristics, and the "X" that accompanies the term *"Design for"* can be any desired characteristic/ skill for such products.

The waste issue in Brazil is complex and multifaceted and the adoption of strategies such as CE, RL and SD can play a key role in mitigating the environmental problems associated with waste generation (Geng *et al.*, 2020; Aguiar *et al.*, 2022; Braga Jr *et al.*, 2023). This is expected not only to reduce the negative environmental impact but also to contribute to achieving the SDGs - Sustainable Development Goals (United Nations, 2015), promoting a more sustainable and equitable future.

To better specify the approaches of this research, *Design for Reverse Logistics* (DfRL) emerges as a branch of DfX that considers, even at the product design stage, aspects associated with the processes and activities that make up Reverse Logistics, as well as their direct positive impacts to promote sustainable competitive advantage. This proposed concept allows sustainability to be more robust, as it considers factors that are little addressed by researchers and designers (Melo *et al.*, 2021).

To achieve and enable DfRL, more specific and assertive information such as Design Guidelines (DG) is needed to enable designers to consider RL demands at an early stage of the PDP, facilitating the execution of RL processes

at the end-of-life stages of products and increasing the chances of these materials being identified, separated, collected and recovered or disposed of in environmentally suitable locations, making them more sustainable. The inclusion of sustainable guidelines in the management of RL activities is a topic of growing interest among researchers (Martins *et al*., 2019).

DG are sets of recommendations on how to apply design principles to provide a positive user experience (*Interaction Design Foundation*, 2016). They provide the direction to be followed, general principles and concepts that serve as a basis for design decisions, a direction and a set of ideas that should be followed during the design phases; this helps to ensure that the design process remains consistent and focused.

The aim of applying DG to product development is to make the results of designers' activities more predictable and supposedly improve results by aiding decisions during the design process, allowing new functionalities to be adapted later without changing the entire concept (Bischof and Blessing, 2008).

Despite their relevance, most information on DG is scattered throughout the literature, in various forms and levels of abstraction and often with an emphasis on products, industry sectors or specific life cycle stages, making it difficult to access and use (Telenko *et al*., 2008) or presented only in text, which increases the difficulty of locating and understanding (Bischof and Blessing, 2008). In addition, there is an opportunity for a solution through new DfX to aid the design process (Sassanelli *et al.* 2020). Thus, by considering DG for RL, it is possible to use the DfRL approach as another alternative (instrument or means) for transitioning towards more circular and sustainable product, process and artefact designs.

Against this backdrop, this research aims to characterize the context of the literature regarding publications on DG for *Design for Reverse Logistics* (DfRL).

2. METHODOLOGY

In order to carry out this research, a Systematic Literature Review (SLR) will be carried out, which is generally used to identify, in the publications considered, evidence of research trends, the evolution of research topics, as well as research *gaps*, helping to provide an overview of current knowledge on the theory, assess the progression of knowledge on the subject and propose potential paths for advancing knowledge (Kraus *et al*., 2022). In particular, this work used the RSL proposed by Tranfield *et al.* (2003), to find a set of DG that meet the DfRL and make it possible to analyse and characterize them from the current context of the literature, in line with the aim of this research. The approach consists of the stages described below, divided according to the objective:

Pilot Review: A search was carried out considering the terms "design guidelines" and "*design for reverse* logistics", as well as some possible synonymous terms, in the *Science Direct, Web of Science* and *Scopus* databases, to survey the literature for DG already proposed for DfRL, as well as to define inclusion and exclusion criteria to be considered in this research.

Research Proposal and Protocol Creation: Based on the information acquired in the previous stage, the search *strings* and scientific bases to be researched were confirmed. It was then possible to define the research protocol which brought together all the information relevant to the article search and selection process, as well as the information to be collected.

Obtaining and Selecting Publications: With the *strings* and databases defined in the protocol, searches were carried out, eliminating duplicate articles and those that could not be accessed. At this stage, five databases were considered: *Science Direct, Web of Science, Scopus*. *Emerald and Springer.* Next, the titles and abstracts of the selected articles were read to check that they were in line with the focus of the research, using inclusion and exclusion criteria.

Data Extraction: In this stage, a full scan of the texts of the selected articles was carried out, to identify and extract the data considered in the research protocol. To this end, a set of research questions (RQ) was considered, with objectives converging with the general objective of this work, as shown in **Table 1**.

Presentation of results: The information extracted from the articles has been synthesized and the results generated were organized in tables, figures and statistics. The parameters considered in this research are those already considered in other research on the subject and aimed at characterizing the current context in the literature, as presented in Appendix A.

Analysis of Results: The results presented in the previous stage were discussed, considering a parallel between information collected and results obtained by other authors involved in studies related to the central theme of this research, to answer the questions initially proposed, as well as present contributions to theory and practice relating to the central theme and the achievement of

the general research objective. The contributions of this stage regarding DG for DfRL were a current overview of research, the current state of research in the area, contributions to achieving the SDGs and sustainability. Finally, the aim is to present the relationship between design and CE and RL, a definition of the associated terms, and the gaps and prospects in the area.

Code	Question	Objective
RQ1	Is the article talking about design guidelines?	Understand whether what is mentioned are design guidelines or some other similar approach;
RQ2	Does the article provide design guidelines?	Understand whether the term is included in the research or just in the title of the papers.
RQ3	Do the identified design guidelines present the form in which they were defined and/or proposed?	Identify methods in the literature for proposing and validating design guidelines.
RQ4	Are the design guidelines identified related to Reverse Logistics (through its activities)?	Understand the current context of the literature on design guidelines that could potentially be correlated to Reverse Logistics.
RQ5	Does the research address design guidelines focused on process, product or artefact?	Understand the context that is considered within the aspects of Product Development Process in research.
RQ6	Are the design guidelines studies related to sustainability?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.
RQ7	In studies on sustainability, what is the main aspect (social, economic and/or environmental) considered?	Understand how sustainability is considered in research related to design guidelines.
RQ8	Are the design guidelines studies related to achieving the Sustainable Development Goals?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.

Table 1: Research questions
Source: Authors

3. RESULTS AND DISCUSSION

Following the methodology presented, specifically in the Pilot Review stage, a preliminary survey was defined (**Table 2**) and then the initial quantitative surveys were carried out, considering the *Science Direct, Web of Science* and *Scopus* databases. These surveys aimed to confirm signs of convergence with the initial research proposal or, if not, to define new directions and parameters.

Search terms	Design Guideline, Guideline, Checklist, Method, Methodology, Design for Reverse Logistics.
Boolean operator	OR, AND
Research base	Science Direct (SD), *Scopus* and Web of Science (*WoS*)
Inclusion Criteria	Talk about any aspect related to design guidelines for reverse logistics.
Exclusion Criteria	Do not address design guidelines for reverse logistics in any way.
Language	No restrictions
Document types	No restrictions
Research period	No restrictions

Table 2: Pilot Review Protocol
Source: Authors

In these research, it was started with an initial *string*, considering the terms presented in the protocol (table 2) and possible substitutions for the term "guidelines", according to Mantese *et al.* (2018), evaluating the number found in the databases considered, as shown in Table 3. For the pilot review, limiting parameters such as language, type of document and period of research were not considered, as this is still an emerging topic in the literature, as reported by Melo *et al.* (2022) and Braga Jr. *et al.* (2023). As can be seen in **Table 3**, the research databases used in this stage did not provide any results when searching with the two *strings*, based on the parameters defined in the protocol, so it was necessary to develop another search strategy capable of confirming an assertive research proposal about the objective of this work.

No.	*String* Uses	Word or Term Search Extracted	Research Bases			
			Scopus	*WoS*	SD	Total
1	("Design Guideline" OR Checklist) AND (Method OR Methodology) AND (Environmental OR Sustainable) AND "Design for Reverse Logistics"	-	0	0	0	0
2	("Design Guideline" OR Checklist) AND "Design for Reverse Logistics"	("Design Guideline" OR Checklist) **AND (Method OR Methodology) AND (Environmental OR Sustainable)** AND "Design for Reverse Logistics"	0	0	0	0

Table 3: *String* Tests for Pilot Review
Source: Authors

To search for related content to obtain an overview of the topic discussed in this research and achieve a strategy aligned with it, the base *string* ("design guidelines") AND ("product design" OR "sustainable design" OR "eco design" OR "design for x") was considered which groups together the themes and areas of study that this work addressed in its introduction. This search once again considered the 3 previous search bases, and the results are shown in **Table 4**.

No.	*String* Used	Database			
		Scopus	*WoS*	SD	Total
1	"design guidelines" AND ("product design" OR "sustainable design" OR "eco design" OR "design for x")	709	160	52	921

Table 4: Pilot Review *String* Test
Source: Authors

The metadata was imported from the research databases and uploaded to the Rayyan platform (www.rayyan.ai), where 216 articles were excluded for being duplicates and the rest were merged into a single file. To make it possible to understand patterns and trends related to this specific topic, considering the remaining 705 articles, the VOSviewer *software* was used, which also allowed, through a bibliometric analysis, the presentation of maps for visualization in networks (van Eck and Waltman, 2010). The visualization of keyword co-occurrence from VOSviewer is shown in **Figure 1**.

As shown in **Figure 1**, the term product design appears prominently, indicating that the results are consistent with the field of product development and interconnected with all other terms, reflecting the unique aspects of this process. Concerning the blue *cluster*, there is a grouping with design guidelines, design process, computer-aided design, optimization and structural design, referring to a set belonging to research that considers aspects of PDP. The other *clusters* do not differ from each other in terms of predominance.

Related to the blue *cluster*, it is possible to see the green *cluster* with the terms design, manufacture, 3D printers, design for x and product development, another grouping that refers to PDP and highlights a relevant term for this research, DfX, confirming alignment and relationship with the trend of analysis on PDP.

Also close by is the red *cluster*, which brings a group of more unique terms related to sustainability, with the presence of ecodesign, life cycle, circular economy, sustainable development, sustainable design, sustainability and decision making. As initially presented in this research and especially concerning the approaches of Telenko *et al.* (2016), there is a potential relationship in the alignment between product design, DG and DfX, considering the terms highlighted and related on the map.

Finally, there is the yellow *cluster*, dealing with aspects related to the terms ergonomics, humans, human engineering, human-computer interaction and user interfaces, which seems to point out that research based on the *string* raised for the creation of these maps also touches on more technological aspects focused on usability and computer data.

In **Figure 2** you can see the time frame of the documents surveyed, where it is relevant to mention the aspects of sustainability, DfX and 3D printing involved in more recent research, dating back to the average year of 2018 and the relationship between the terms product design and design guidelines permeate the average time between the years 2012-2014.

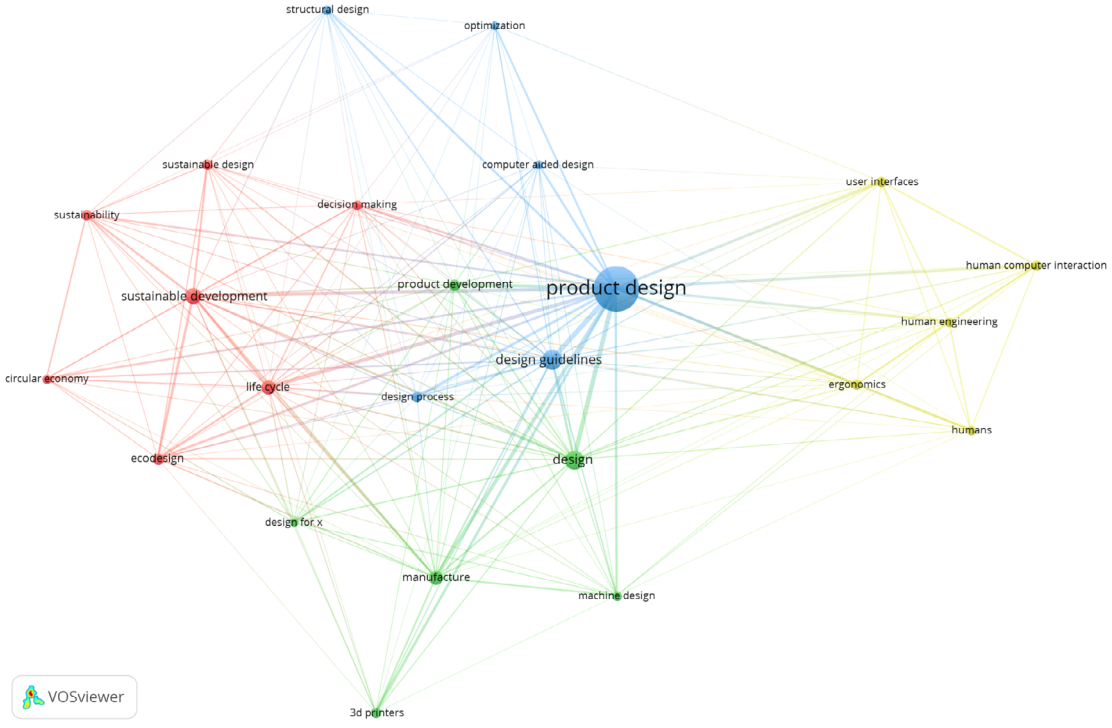

Figure 1: Cooccurrence network Keywords
Source: Data generated by VOSViewer (2023).

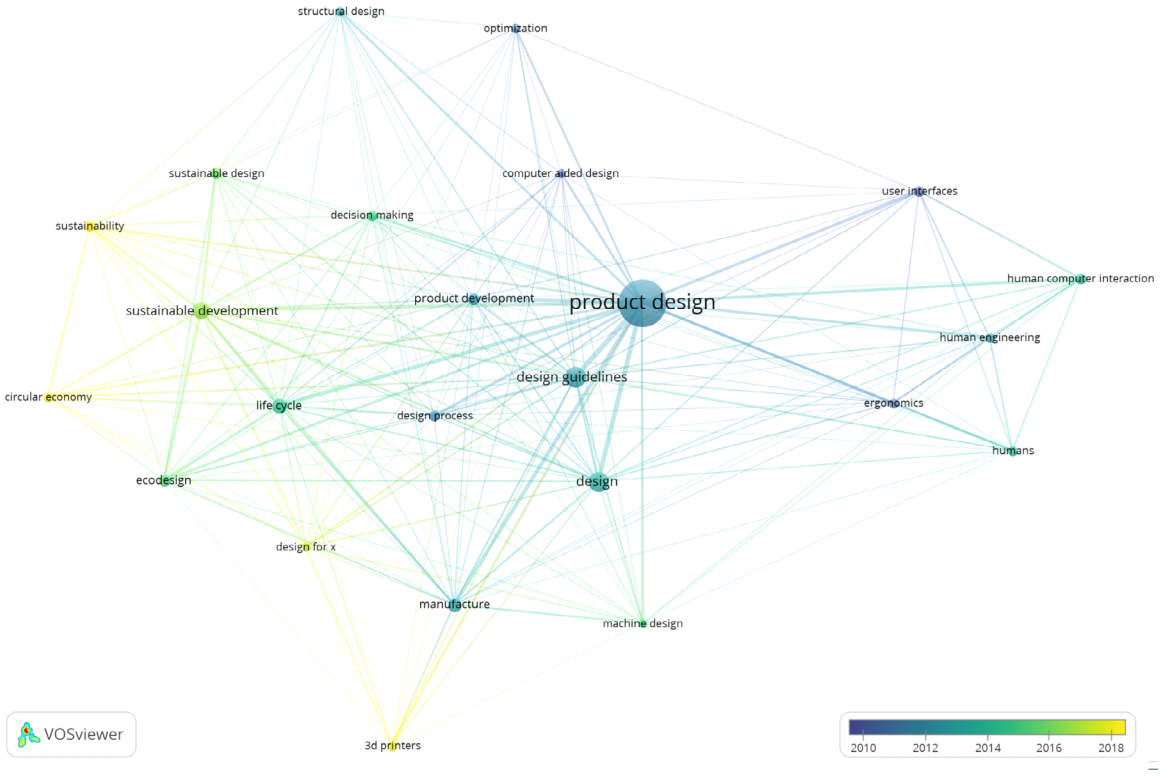

Figure 2: Keyword Cooccurrence Network (Average Date of Terms)
Source: Data generated by VOSViewer (2023).

It is therefore possible to conclude that this group of terms involves recent research and that they are in the average time of ten years to date. At the end of the visualization, analysis and interpretation of the scientific mapping generated by the VOSviewer *software*, new parameters were obtained for the definition of keywords capable of guiding a new search strategy aimed at results in line with the objective of this research.

Understanding that, to achieve the objective of this research, three themes must be analyzed: Reverse Logistics, DfX and DG, we sought a research path that presented some correlation between them, considering the results obtained in the bibliometric analysis carried out in previous stages, to guide the search in the literature for DG for DfRL that could be analyzed and characterized after identification.

As presented by Melo *et al.* (2022), RL is made up of ten activities that enable the process, as follows: integration, acquisition, inbound sorting, collection, transportation, inspection/testing, storage, disassembly, classification and redistribution. Given that these activities constitute RL, the research focused not only on these processes but also on addressing topics related to DfX, DfRL, or DG. Braga Jr. *et al.* (2023) proposed a set of 15 DfX potentially related to RL activities based on the association of definitions of these activities with the definitions of DfX identified in the literature. They are Design for Procurement, Design for Supply Chain, Design for Disassembly, Design for End of Life, Design for Remanufacture, Design for Testability, Design for Storage and Distribution, Design for Logistics, Design for Supportability, Design for Modularity, Design for Mass Customization, Design for Reuse, Design for Materials Conservation, Design for Maintainability/ Maintenance and Design for Industrial Symbiosis. These authors also suggested that further research should investigate DG for DfRL, followed by a comparative analysis of these with the guidelines of other DfX approaches associated with DfRL in this study. For these authors, this will allow a more consistent assessment of the level of contribution of each design guideline, since the definitions of DfRL and DfX will be at the same level of detail.

Therefore, the term Design for X (DfX) was considered instead of Design for Reverse Logistics (DfRL), where "X" was replaced by the 15 characteristics/skills "X" potentially associated with RL activities, according to Braga Jr. *et al.* (2023).

Through this strategy, it is believed that it is possible to identify DG that meet the RSL since they consider the demands of the activities needed to make it possible. In this way, two different possible *strings* were tested, considering two new bases to add more documents and give more scope to the RSL, and the quantities obtained were evaluated, as described in **Table 5**, also considering the result generated in the scientific maps.

No.	*String* Base	Word or Search Term Extracted	Database					
			Scopus	*WoS*	SD	*Emerald*	Springer	Total
1	("Design Guideline") AND ("product design") AND ("Design for X*")	-	13	0	0	42	354	409
2	("Design Guideline") AND ("Design for X*")	("Design Guideline") AND ("product design") AND ("Design for X*")	52	1	9	53	497	612
*15 characteristics/skills X associated with RL activities, according to Braga Jr. *et al.* (2023)								

Table 5: *String* Test and Quantitative Result per Database

Source: Authors.

Based on the obtained result, to develop the second stage of this research, the quantity found was evaluated to ensure the research objective was met. The second *string* was chosen because it yielded a broader search result for potential publications identified in the initial survey of the considered databases. As part of this stage, a new research protocol was elaborated and defined based on the parameters as follow.

- **Search Terms:** Design Guideline, Design for End of Life, Design for Industrial Symbiosis, Design for Logistics, Design for Maintainability/Maintenance, Design for Mass Customization, Design for Modularity, Design for Procurement, Design for Remanufacturing, Design for Reuse, Design for Supply Chain, Design for Supportability, Design for Testability, Design for Disassembly, Design for Storage and Distribution, Design for Materials Conservation;
- **Boolean Operator:** OR, AND;
- **Research Database:** Science Direct (SD), *Scopus*, Web of Science (*WoS*), Springer, *Emerald*;
- **Inclusion Criteria:** Discuss any aspect related to DG for DfX related to RL activities;
- **Exclusion Criteria:** Do not address, in any form, DG for DfX related to RL activities;
- **Parameters:** Authors; country; product; process; artifact; cited guidelines; defined guidelines; DG associated with RL; DG associated with sustainability;
- **Language:** English;
- **Document Types:** Research Articles and Reviews;
- **Period:** No restrictions.

By applying the limiting parameters of format and language, as outlined in the previous paragraph, the final search result, based on the defined *string*, is shown in **Table 6.**

In the Obtaining and Selecting Publications stage, searches were carried out based on the results shown in **Table 6**. After applying the inclusion and exclusion criteria, only five articles were considered suitable for the next stages of the research method, where only one was identified as duplicated and excluded, and one was inaccessible. **Table 7** shows the list of selected articles.

String Base	Database					
	Scopus	*WoS*	SD	*Emerald*	Springer	Total
("Design Guideline") AND ("Design for X*")	25	0	5	48	76	**154**
*15 characteristics/skills X associated with RL activities, according to Braga Jr. *et al.* (2023)						

Table 6: String Results and Number of Articles per Database

Source: Authors.

Code	Title	Authors	Year	Search DfX
A1	Design for circularity and durability an integrated approach from DFX guidelines	Jaime A. Mesa	2023	Modularity
A2	Inventive solutions for remanufacturing using additive manufacturing - ETRIZ	Srujana Kandukuri, Elif Elçin Günay, Omar Al-Araidah, Gül E. Okudan Kremer.	2021	Remanufacturing
A3	Multiple generation life cycles for product sustainability	T.F. Go, D.A. Wahab, H. Hishamuddin.	2015	Modularity Disassembly
A4	Inventive Guidelines for a TRIZ-based Eco-Design matrix	D. Russo, C. Rizzi, G. Montelisciani.	2014	Disassembly
A5	Development of integrated design for disassembly and recycling in concurrent engineering	Ke-Zhang Chen	1999	Disassembly

Table 7: Selected articles

Source: Authors.

Given the low number of surveys, it was decided on a new strategy to try to expand the number of surveys obtained by carrying out a snowball search, a survey technique used in qualitative research that allows us to reach populations that are little known or difficult to access, proving to be useful for investigating samples that are still little known or explored, helping with a general understanding of factors associated with the topic (Bockorni; Gomes, 2021).

Therefore, in the full scan of the references cited in the five results initially obtained, an analysis was carried out to look for other references that corroborated the theme of this work.

Eight new references were identified with potential contributions and conformity with the first five articles selected. One article was also excluded due to duplication (A2A-A3B), effectively adding up to seven new articles which now make up a new total of twelve results for extraction, presentation and analysis, as shown in **Table 8**.

Code	Title	Authors	Years
A1	**Design for circularity and durability an integrated approach from DFX guidelines**	Jaime A. Mesa	**2023**
A1A	Design for sustainability (DFS): the intersection of supply chain and environment	Andrew N. Arnette, Barry L. Brewer, Tyler Choal.	2014
A1B	A methodological approach to design products for multiple lifecycles in the context of circular manufacturing systems	Farazee M.A. Asif, Malvina Roci, Michael Lieder, Amir Rashid, Aleš Mihelič, Simon Kotnik.	2021
A1C	Design for Circularity Guidelines for the EEE Sector	Anton Berwald, Gergana Dimitrova, Thijs Feenstra ,Joop Onnekink, Harm Peters, Gianni Vyncke, Kim Ragaert.	2021
A1D	Addressing circular economy through design for X approaches: A systematic literature review	Claudio Sassanelli, Andrea Urbinati, Paolo Rosa, Davide Chiaroni, Sergio Terzi.	2020
A1E	EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development	Conrad Luttropp, Jessica Lagerstedt.	2006
A2	**Inventive solutions for remanufacturing using additive manufacturing: ETRIZ**	Srujana Kandukuri, Elif Elçin Günay, Omar Al-Araidah, Gül E. Okudan Kremer.	**2021**
A2A (A3B)	A tool to implement sustainable end-of-life strategies in the product development phase	A. Gehin, P. Zwolinski, D. Brissaud.	2008
A3	**Multiple generation life cycles for product sustainability**	T.F. Go, D.A. Wahab, H. Hishamuddin.	**2015**
A3A	Design for environment (DfE): strategies, practices, guidelines, methods, and tools	DP Fitzgerald, JW Herrmann, PA Sandborn, LC Schmidt, TH Gogoll.	2007
A4	**Inventive Guidelines for a TRIZ-based Eco-Design matrix**	D. Russo, C. Rizzi, G. Montelisciani.	**2014**
A5	**Development of integrated design for disassembly and recycling in concurrent engineering**	Ke-Zhang Chen	**1999**

Table 8: Final results of the selected articles

Source: Authors.

Finally, after investigating all of these options, it was possible to deduce, based on Khatcherian *et al.* (2022), that the low number of articles on this topic may be similar to the condition exposed by the authors, where no results or few results were obtained, which qualifies this situation as an occurrence resulting from a recent topic, still controversial among the scientific community and/or a concept not yet recognized or vague by professionals in the areas involved, or, finally, because it covers different areas of knowledge, it is complex to study the whole set and form an overall conclusion. These authors also contribute to the fact that an RSL does not return results, emphasizing the importance of more research to verify the subject and that possibly only part of the complexity surrounding it has been identified.

Based on these results, it was possible to begin the Data Extraction and Presentation of Results stages by scanning the full texts of the twelve classified articles in search of answers to the research questions initially defined. From the new articles collected, it was possible to discover new DfX associated with this research that can be added to the contributions to the initial fifteen DfX, considered by Braga Jr. *et al.* (2023), namely:

- A1: Design for Circularity and Durability;
- A1A: Design for Sustainability;
- A1B: Design for Multiple Lifecycles;
- A1C: Design for Circularity;
- A1D: Design for Supply Chain, Design for Circular/ Sustainable SC, Design for System Change, Design for Resource Efficiency and Conservation, Design for Slowing Lifecycle, Design for Long life Use of Products, Design for Maintenance, Design for Product-life Extension, Design for Reliability, Design for Safety, Design for Multiple Life Cycles, Design for Disassembly and Reassembly, Design for Remanufacturing, Design for Remake, Design for Recovery, Design for Recycling, Design for End-of-Life, Design for Adaptability, Design for Standardization, Design for Compatibility, Design for Modularity, Design for Upgradability, Design for Sustainability, Design for Environment and Design for Social Responsibility;
- A1E: Design for Environment;
- A2A (A3B): Design for Environment;
- A3: Design for Multiple Life-Cycles;
- A3A: Design for environment.

As for the debate based on the research questions, following the protocol, the Results Analysis stage can begin. For RQ1 and RQ2, which investigate whether the articles address and present DG, all twelve articles address DG, but four do not present them in their text, a result that still allows us to understand that the term DG is pertinent and corresponds to what was presented in the introduction of this research, but it is still pending to explore and present its contrasts concerning other terms that were also identified in the text, such as requirements, considerations, rules, recommendations, principles, propositions and tools.

The four articles that did not present DG (A1A, A1B, A1D, A2A-A3B) raise important discussions about the relevance and characterization of DG related to their respective DfX, in line with the theme of this research.

Article A1A discusses the fact that the DFX literature is extensive, covering many topics in various disciplines and this complexity makes it difficult for researchers and practitioners to keep up with developments in DFX, considering that some research covers similar ideas but under different names, and even techniques with the same name often take on different meanings, approaches and DG. A1B doesn't present any DG either, for example, but it does present the need to understand why and how products reach their end of life. The authors also state that in the linear approach, it is not a designer's priority to think about the value recovery phase, so they should be given the possibility to synchronize the objectives of the intended project with the planning of a product's multiple life cycles.

Accordingly, article A2A (A3B) reports that the overall recovery process should be foreseen as soon as possible, especially during the design phase, taking into account the different stages from the collection to the use of the recycled materials, the assembly of restored or reused components into new products and the sale of remanufactured products. After all, product recovery is not just a question of reprocessing a used product, but also of transporting it to a place where recycling is feasible, for example. Designers need simple and efficient methods that can be adapted to their daily tasks and skills, considering aspects according to the DfX approaches considered. The A3A article adds that there is a need for a simple DfE tool that forces designers to consider environmental issues when designing products, so integrating a DG/checklist document into a new DfE process is a simple and effective way of highlighting environmental concerns. However, this document needs to be company-specific and systematically integrated into the product development process. All these works address an opportune scenario for discussing DG and their contextualization.

About RQ3, which asks whether the DG identified present how they were defined and/or proposed, it can be concluded that the articles that present DG also present propositions through associations with other concepts and DfX, in which they demonstrate how DG were proposed based on some already existing ones, thus configuring a result of proposing new ones based on this adaptation and/or adaptation. This group of articles clarified how DG should be presented, from their writing to their visual configuration. Specifically, A4 states that project guidelines should be structured with a clear and complete goal, with a description containing tools, strategies, best practices and examples. Article A1E confirms these aspects by gathering and presenting a compilation of documents and references as a basis for understanding and visualizing project guidelines.

Still, concerning RQ3, one article presents a case study (A1), another an example (A4), and a third (A2) defines a route for implementing the DG for the design process. Only in these three cases was there any validation of the proposition of DG, but all of them are still insufficient. This is reinforced by article A1, which suggests that future research efforts should consolidate and analyze the implementation of these DG. This is reinforced by article A1E which points out that there is a lot of interest in sustainable product development and many design tools and guidelines have been suggested, but it is not clear whether these tools are being used and whether they have any real effect on the development of product systems.

About RQ4, "Are the identified DG related to RL (through their activities)?", it can be concluded that the current context of the literature on DG is potentially correlated to RL from the disassembly activity, cited in seven articles. The activities of integration, acquisition, inbound sorting, collection, transportation, inspection/testing, storage, classification and redistribution, mentioned by Melo *et al.* (2022), are discussed in articles A1A, A1D, A2A (A3B), A3 and A5.

The A1A article reports that many works focus on narrow aspects of product design considerations and do not consider many other facets of product design, production, delivery, use and end-of-life. From a broader perspective, it was previously understood that post-production was a matter of infrastructure rather than product design. However, it is now clear that design decisions have a direct impact on the maintainability and reliability of the product, interfering with the frequency of service and product support. After all, product design affects the amount of service required and the mode of delivery and the concept of Design for Logistics (DFL) shows that product design impacts the packaging and transportation of a product and incorporating these considerations into the design can make distribution more efficient and reduce costs. The authors state that business processes seem to be seen as independent of the design process, but it should be recognized that product design affects supply chain activities.

This article also discusses the role of RL, which is increasingly being recognized as important for dealing with product service and support, returns and their recovery at the end-of-life stage, to support remanufacturing, recycling and disposal, facilitating the achievement of goals from an environmental, sustainability and economic point of view. Within this article, the authors mention Rogers and Tibben-Lembke (2001) regarding the differences between RL and green logistics and report that barriers to RL include a lack of importance and attention from management and a lack of policies, systems and resources to implement it, but it needs to be considered in the design process. Also, according to the A1A article, RL is becoming increasingly important for implementing returns and moving products that will be remanufactured or recycled at the end of their useful life, and DfRL raises questions about how product design relates to RL, going beyond the choice of channels and methods for accepting returns and recovery. Therefore, making DfRL a design technique has the potential to reduce costs by planning and developing the infrastructure and activities that the supply chain must carry out.

Next, the A1D article states that methods and tools that support the systematic integration of products and services from a circular perspective are still under development, and are in an under-researched research context, even if they deserve more attention from both researchers and practitioners. The article concludes by presenting the promotion of RL and the definition of the useful life of products as a strategy, converging with the need for new DfX methods and tools to satisfy the very heterogeneous issues present in the design process. Strategies mentioned to support the design decision-making process or to find a balance between the various existing DfX skills or reveal their unique limitations.

Article A2A (A3B) presents the possibility of considering RL channels, product and component disassembly processes or material recycling, moving towards product recovery carried out by the manufacturer itself or through partnerships with independent stakeholders specialized in various activities so that it is possible to maintain control over its products. As an obstacle, the article points

out that RL and disassembly are especially sensitive, as they often do not belong to the core business, and that the recovery process must be foreseen as soon as possible, especially during the design phase.

Article A3 cites RL and Reverse Engineering (RE) as contributors to considering the use of existing direct supply chain facilities and transportation systems as much as possible for the reverse supply chain, sorting used products as early as possible in the recovery chain and reducing the volume and quantity of materials going to landfill, as well as considerations for alternative uses of used products or waste. He also states that designing for the return of a product and establishing a single system for this to happen increases its chances of being reused, remanufactured or recycled, confirming his proposition and the relevance of designing for Multiple Life Cycles (MLC).

Article A5 states that although the costs of collecting and transporting waste are beyond the control of product designers, it is a factor that is related to the value of the materials recovered and consequently to their responsibilities. Therefore, products should be designed with these two aspects in mind, plus the possibility of separating or disassembling the parts, to reduce disassembly costs and expand the possibilities for reuse and recycling.

Still, to RQ4, article A1 presents guidelines for circular and durable designs and points out that it may be interesting for future work to consider and develop a framework for software, services and product-service systems since the rules relating to the incorporation of design are still mainly focused on the architecture and geometry of the product and the definition of materials.

Moving on to the data extraction activity for RQ5, which asks whether the research addresses DG for processes, products or artefacts, the results showed some articles that deal with products and processes, but not artefacts. It is important to mention that there is a contradiction between the articles analyzed, where some point out the need to define DG specific to a product context and others believe that the way forward is to develop a more comprehensive DG. It is believed that this lack of convergence is because there is no standardization in the literature of the hierarchy of categorization of information used in PDP, namely: rules, guidelines, checklists, checklists and others, reinforcing the need to understand how DG are currently characterized by researchers.

As for RQ6 and RQ7, which investigate issues associated with understanding the panorama of project guidelines concerning sustainability and which aspects of sustainability, the articles present content in line with sustainable development, with priority given to the environmental aspect and a total of six articles discussing the economic aspect. Only article A1A also presents the social aspect of sustainability, according to Elkington (1994) concerning the Triple Bottom Line.

Within this theme of RQ 6 and 7, some articles have interesting content to highlight. A2A (A3B), for example, it presents that designers are often not environmental experts and don't have the knowledge to design products that are more environmentally friendly and adapted to recovery strategies such as reuse, remanufacturing and recycling. The authors report that although the DfE has added environmental awareness to the company, it is still a long way from the work of a designer, as most methods are limited to measuring environmental impacts which can only be explored by specialists.

Article A3A points out that most product development organizations should treat environmental objectives in the same way as they treat safety issues. In addition, the A1E article states that designers hold the key to sustainable product development through EcoDesign, where many tools have been built for this purpose. They also state that most are rarely used, mainly due to the lack of sustainability-oriented requirements in product specifications. They report that there are many tools and DG suggested, but it is unclear whether these tools are being used and whether they have any real effect on the development of product systems.

Concluding the debate on RQ 6 and 7, the A1A article points out that the information dealt with and related to various DfX has provided an exchange of sustainability and the environment, but only focuses on one pillar of sustainability, ignoring the other two (social and economic) which can lead to projects that are not economically viable or involve negative social impacts. According to the authors, as the role of sustainability in business has grown, the recognition that product design plays a key role in helping to achieve sustainability is indisputable. They also conclude that the DfX literature on the three pillars of sustainability is lacking in its approach to this topic. Therefore, as the importance of supply chain activities has grown, DfX techniques have expanded to assess the impact of product design on these activities.

Also discussed in A1A, the concept of disposal, in which a product is discarded at the end of its life cycle, should be given more attention by researchers, first considering whether the materials to be discarded are those that cannot be revalued and represent the "leftovers" of this process, or having the correct vision and

understanding, according to the literature, that a product that does not fit into the first case should be disposed of safely. Complementing the analysis of sustainability, the authors noted that the need to recognize social equity has increased in recent years, but still lags behind economic and environmental design issues. Regarding a DfX for social equity, the authors state that its development goes beyond the scope of a more traditional DFX, aiming to change opportunities and responsibilities and eliminate restrictions or negative social aspects.

Finally, in RQ8, which aims to identify whether the DG are related to the achievement of the SDGs, a contribution to the achievement of the SDGs was identified in all the articles that discuss DG, since the interventions proposed to product designs induce improvements that reduce the negative impact of the occurrence of solid waste. However, the authors of these articles do not directly mention the achievement of the SDGs in their texts. It should be noted that in the case of articles A1E, A2A (A3B), A3, A3A, A4 and A5, these publications date from before the SDGs were discussed by the UN.

In addition to the above information, the articles analyzed presented other important considerations for this work, which were not foreseen in the research protocol. According to article A1, an obvious challenge is the integration of geometry and materials rules for more circular products, especially for complex products made up of several sub-assemblies. Similarly, design rules must be generated for non-tangible products, such as software and services, to cover CE issues related to resource consumption and sustainability performance.

According to the A1A article, the current literature is deficient in addressing social equity and RL, and these areas should be further developed, including the need for alignment with theory and empirical testing, as well as exploring the relationships between DfX techniques and sustainability dimensions. According to the authors, the original DfX approaches emerged as a means of making the operations and production aspects of product creation more efficient, while reducing time, costs and errors, and should now move towards addressing and addressing sustainability issues. The authors point out that one of the major findings is that DfX is still very much focused on professional practice, and further research is needed, perhaps confirming why there were few results selected in this research.

Although some new approaches may look beyond the product to the supply chain, such as Design for Supply Chain (DfSC), they are not as prominent in the literature as a DfX topic as Design for Logistics (DfL). Finally, the authors mention that even more neglected in the literature, in addition to DfSC and DfL, is DfRL, because although DfL can affect the RL process, there are many scenarios in which used components, recyclable materials or remanufactured end items must return through the supply chain, and this movement, to comply with regulations, capture remaining value or to remove hazards from the community, is essential to the functioning of the closed-loop supply chain.

In article A1B, the research identified that there is a strong synergy between the concepts of product design strategies, product obsolescence and product end-of-life options. Designing a product that can be used in multiple life cycles is not an established practice in PDP and there is a lack of methodological approaches capable of supporting designers in designing products for multiple life cycles. The authors conclude that designers should seek a balance between design strategies and end-of-life options, to improve value recovery in each product life cycle (PLC).

Also confirming and adding to the previous articles and the subject of this research, article A1D states that, in the context of the Product-Service System, DfX has rarely been considered by experts, and new design knowledge related to new technologies is needed to guide the joint search towards CE and Industry 4.0.

The A1E article then points out that DG, checklists and other tools have been used in product design for a long time and many other purposes besides eco-design. These are tools that differ in complexity and structure, sometimes being very simple, like a few practical rules, and sometimes constituting a complete, comprehensive and complex system, during this, engineers and designers have also created their checklists and tools to document experiences and facilitate cooperation in product development teams. Therefore, the need to develop clear solutions for DG was realized.

Still on DG, article A2A (A3B) reports that, according to DfE guidelines, designers must integrate the environmental variable into all their tasks, going through guidelines that do not indicate how to design the product itself, but rather recommendations on what the product should look like and how to check the guarantee in respect of the envisaged policy. Given these considerations, documents that record all this, such as the research object of the authors in question, should be a "living document".

In conclusion, it was possible to extract, present and analyze the data under the protocol and the use of the snowball technique brought greater scope and reach to the results of the work, proving to be a fruitful alternative. After

presenting the discussion and considerations on the articles researched, it was possible to reach some conclusions about achieving the objectives set out in the RQ. **Table 9** summarizes the information presented in order to better visualize the consolidation of the results of this research.

Code	Question	Objective	Results achieved
RQ1	Is the article talking about design guidelines?	Understand whether what is mentioned are design guidelines or some other similar approach;	Design guidelines are presented in the literature as well as other associated terms.
RQ2	Does the article provide design guidelines?	Understand whether the term is contemplated in the research or only makes up the title of the papers.	Not all the articles discuss design guidelines, associating this term with other information outside the scope of this research.
RQ3	Do the identified design guidelines present the form in which they were defined and/or proposed?	Identify methods for proposing and validating design guidelines in the literature.	The information obtained is not sufficient, reliable or valid to identify a method already established in the literature.
RQ4	Are the design guidelines identified related to Reverse Logistics (through its activities)?	Understand the current context of the literature on design guidelines that could potentially be correlated to Reverse Logistics.	The current literature does not sufficiently cover potential design guidelines for Reverse Logistics activities.
RQ5	Does the research address design guidelines focused on process, product or artefact?	Understand the context that is considered within the aspects of Product Development Process in research.	The literature surveyed covers products and processes but is divided into approaches for specific products and more general approaches.
RQ6	Are the design guidelines studies related to sustainability?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.	The literature presented an already present and opportune scenario for stimulating sustainable development.
RQ7	In studies on sustainability, what is the main aspect (social, economic and/or environmental) considered?	Understand how sustainability is considered in research related to design guidelines.	It was possible to understand that sustainability is dealt with primarily in its environmental and economic aspects, and there is a gap in the social aspect.
RQ8	Are the design guidelines studies related to achieving the Sustainable Development Goals?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.	The results converge towards sustainable development and there is a potential relationship with the achievement of the Sustainable Development Goals.

Table 9: Consolidation of Research Results

Source: Authors.

It is also interesting as a contribution to present the terms associated with the term "design guidelines" identified in the literature surveyed. It was noted that the word "guideline" is still closely associated with other terms in the literature. As previously mentioned, this is possibly due to the dispersion and lack of clarity about the hierarchy of project-related information. Understanding the need to establish the use of the term "design guidelines" for recommendations for the application of design principles and decisions, avoiding distorting the research and making it difficult to identify in the vast literature, it is important to understand that terms such as rules, principles, strategies, checklist, method, etc., take on meanings in this context that do not characterize the intended recommendations.

Still, based on the themes that run through and contribute to the development of this research, it was possible to see opportunities for research into the relationships between design, CE and RL. Considering the results obtained in the literature investigated, there is little relationship between the themes when it comes to DG. The quantitative analysis shows that designers do not discuss CE when it comes to DG. The professionals who carry out this scientific and technical discussion are engineers. Understanding the transformations and results possible through CE and RL in the PDP, we can see the

potential and need for these topics to be addressed more frequently and in greater depth when proposing DG, to maximize the scope of a scenario in which designers dialogue more closely with aspects of sustainable development. According to Farazee *et al.* (2021), many research contributions are rapidly emerging that describe the role of design in the context of SD, but existing design paradigms are still developed to support designers in product design for a single life cycle. Furthermore, for these authors, paradigms such as SD and Ecodesign still approach the design process for linear systems, thus lacking the perspective of maintaining value over time, which is a fundamental principle in CE.

However, it is also possible to conclude that this gap exists given the perception that there is no satisfactory exchange of information between designers and researchers. It is assumed that some information about product development is retained in the industrial/company environment and does not reach researchers who can disseminate this information in scientific circles, thus boosting the capitalization of knowledge on the subject. Some DG for DfRL, for example, may exist, and even be used and validated. However, designers and/or businesspeople don't consider this information relevant, don't see the contributions that sharing it can make, or don't even record it, so it can't be recognized or identified. This understanding also stems from market observation, where interesting design solutions are seen that are potentially related to RL activities, such as disassembly, but no scientific information is found on these products.

The discussion about the relationship between CE, RL and the exchange of information in technical and scientific circles can lead to another reflection on the professional training and responsibilities of designers. There is a need for adjustments in the pedagogical projects of courses that develop competencies, skills and attitudes associated with the training of product designers so that it is possible to reduce the knowledge gaps between their technical activity and the understanding of their responsibilities and contributions to strengthening the relationship between PDP and sustainable development. Suitable interventions can reduce the knowledge gaps between designers and researchers.

Moving on to the results, it is possible to conclude that studies aimed at proposing DG for DfRL are still in their infancy since there is a lack of duly formalized means in the literature related to a safe proposition method and subsequent tested validation. However, in addition to characterizing the current context of the literature on the subject, it was also possible to learn about other potential DfX related to RL activities. Future research could look into this new relationship, according to the research model developed by Braga Jr. *et al.* (2023). Finally, the results generated contributions to theory and practice related to the research theme. As a contribution to theory, there is a need to properly develop terms and hierarchize DG and other methods, mainly as a way of facilitating the development of and access to design instructions and recommendations aimed at specific objectives. It is understood that DG have been in the literature for some time, and it is important to develop them through new DfX, with objectives that contribute to the development of circular products and the achievement of the SDGs, covering environmental, economic and social aspects of sustainability. As a contribution to practice, in line with the discussion presented above, there is a significant opportunity and need for the training of designers to include subjects aligned with sustainable development and, at a professional level, for companies and designers to be motivated to share more information about PDP so that there is greater collaboration between the technical and scientific world, strengthening a useful contribution that is aligned with the reality of sustainable product design.

4. CONCLUSIONS

The research in question brought to light important considerations about the intersection of product design, Reverse Logistics (RL) and Circular Economy (CE), especially in the context of DG for RL, under the concept of Design for Reverse Logistics (DfRL). By analyzing the literature and conducting a Systematic Literature Review (SLR), gaps, trends and potential contributions to theory and practice of Sustainable Design (SD) and the development of more circular and sustainable products were identified.

One of the main conclusions of the research is that there are few studies on specific guidelines for DfRL and, although there are mentions and related approaches, no formalized methods have been identified in the literature for proposing and validating these guidelines. This is an aspect that deserves attention and future development, considering the growing importance of RL and CE in solid waste management and in promoting sustainability. The need and relevance of designing a product that can be used in several life cycles was perceived, as a practice that is not yet established in the PDP and lacks methodological approaches capable of supporting designers in the

design of these products. Designers must seek to improve the recovery of value in each PLC.

In terms of contributions to theory, the need for the appropriate development and hierarchization of terms and methods related to DG is highlighted, to facilitate access to and application of these guidelines by designers. In addition, the research highlighted the importance of exploring new DfX approaches aligned with and potentially contributing to DfRL, with a focus on circularity and achieving the Sustainable Development Goals (SDGs), considering the environmental, economic and social aspects of sustainability.

In practice, there is an urgent need to promote greater collaboration between companies, designers and the academic community, encouraging the sharing of information and experiences related to the product design process. This collaboration can strengthen useful input aligned with the real needs of product design, driving the transition to a more sustainable and circular production model.

In summary, the study has provided insights into the guidelines for DfRL, highlighting areas for improvement and opportunities for future research. By promoting a critical reflection on current practices and the challenges faced, this work can contribute to significant advances in the integration of RL in the early stages of the design process, driving the adoption of more sustainable and circular practices in industry and society. As a research limitation, other future work could reproduce the research path presented in this paper, exercising the use of other terms that have been identified here, seeking to achieve more information about guidelines for DfRL.

As a proposal for future work, it is relevant to group the DG identified, compile them and apply them in a case study to gather the necessary information for the proposition and safe validation of guidelines for the DfRL. It is also possible to further investigate the relationship between the newly identified DfX and DfRL.

In addition, it was possible to identify other research opportunities in terms of alignment with aspects of sustainability, especially the social aspect and contributions to achieving the SDGs and exploring new relationships between design, CE and RL, as well as the need for greater integration between designers and researchers to share knowledge and experiences.

The professional training of designers is also a key issue, highlighting the importance of adjusting educational curricula to enable future designers to deal with the challenges and responsibilities associated with sustainable development. A common practice is for designers to work alongside specialists and users, seeking to achieve more integrated and efficient solutions within the context of the project, and at times the literature points to this as a weakness in the designer's professional practice, but it constitutes a necessary method and practice.

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MGVM: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization and writing - original draft.

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VWBM: investigation, methodology and validation.

LIC: investigation, methodology and validation.

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