Revista Thema
v.23 | n.1 | 2024
p.311-332

DOI: http://dx.doi.org/10.15536/thema.V23.2024.311-332.3545

ISSN: 2177-2894 (online)

ENGENHARIAS

A systematic review of sustainability and ecodesign in production processes: exploring integrated environmental management tools

***Uma análise sistemática da sustentabilidade e ecodesign em processos produtivos**: explorando ferramentas de gestão ambiental integradas*

Maurício Sandim[1]
https://orcid.org/0000-0001-8074-0233 http://lattes.cnpq.br/3056457880111706

Ênio Leandro Machado[2]
https://orcid.org/0000-0003-0140-4966 http://lattes.cnpq.br/6922571767923420

Jorge André Ribas Moraes[3]
https://orcid.org/0000-0002-9505-8883 http://lattes.cnpq.br/9865102081473789

Liane Mahlmann Kipper[4]
https://orcid.org/0000-0002-4147-892X http://lattes.cnpq.br/1353629457597527

Carlos Alexandre Lutterbeck[5]
https://orcid.org/0000-0002-7709-7918 http://lattes.cnpq.br/3747695210156927

Sandra Elisia Lemões Iepsen[6]
https://orcid.org/0000-0002-7950-4177 http://lattes.cnpq.br/1633972114339163

Guilherme Lemões Iepsen[7]
https://orcid.org/0009-0008-0373-4364 http://lattes.cnpq.br/8970059223175244

Carine Baggiotto[8]
https://orcid.org/0000-0002-6986-7580 http://lattes.cnpq.br/9989347980251642

[1] Universidade de Santa Cruz do Sul – UNISC, Santa Cruz do Sul/RS – Brasil. E-mail: mauriciosandim@hotmail.com
[2] E-mail: enio@unisc.br
[3] E-mail: jorge@unisc.br
[4] E-mail: liane@unisc.br
[5] E-mail: carlosalexandre@unisc.br
[6] E-mail: siepsen@mx2.unisc.br
[7] E-mail: giepsen@mx2.unisc.br
[8] E-mail: cbaggiotto@unisc.br

ABSTRACT

The application of tools in the production process in pursuit of sustainability in companies generates not only environmental benefits, but also social, economic and governance ones. The main objective of this study was to identify and analyze the relationship between the themes of sustainability and eco-design in production processes, relating them to environmental management tools. The methodology used in the research was the Systematic Literature Review (SLR), and through the PRISMA meta-analysis it was possible to consider new aspects to answer the research question: “What relation exists between the topics of sustainability and eco-design in productive processes?” and “Which environmental management tools are related to these topics?”. Based on the articles studied, it was possible to verify that tools and techniques applied to the production process, such as the use of eco-design concepts and techniques in the conception of products, and the identification of environmental impacts through inventories of procedures and Life Cycle Assessment (LCA) management, all of which improves processes, and reduces energy consumption, waste generation, production cost and raw materials.

Keywords: sustainability; eco-design; tools; production process; life cycle analysis.

RESUMO

A aplicação de ferramentas no processo produtivo buscando a sustentabilidade nas empresas gera não apenas benefícios ambientais, mas também sociais, econômicos e de governança. O objetivo principal deste estudo foi identificar e analisar a relação entre os temas da sustentabilidade e do ecodesign nos processos produtivos, relacionando-os com ferramentas de gestão ambiental. A metodologia utilizada na pesquisa foi a Revisão Sistemática da Literatura (RSL) e através da meta-análise PRISMA foi possível considerar novos aspectos para responder às questões de pesquisa: “Qual a relação existente entre os temas sustentabilidade e ecodesign em processos produtivos?” e “Quais ferramentas de gestão ambiental estão relacionadas a estes temas?”. Com base nos artigos estudados, foi possível verificar que ferramentas e técnicas aplicadas ao processo produtivo, como a utilização de conceitos e técnicas de ecodesign na concepção de produtos e processos, e a identificação de impactos ambientais por meio de inventários de processos e de Análise de Ciclo de Vida (ACV) melhorando processos, reduzindo consumo de energia, geração de resíduos, custo de produção e uso de matéria prima.

Palavras-chave*: sustentabilidade; ecodesign; ferramentas; processo produtivo; avaliação do ciclo de vida.*

1. INTRODUCTION

Technological advancements in industries have grown a lot in the last decades, generating environmental disturbances. As a consequence, companies are becoming more responsible with the environment, aiming to reduce environmental impacts through development of clean technologies (Casner; Livotov; Silva, 2018; de Mello Santos *et al.*, 2022; Sahoo; Kumar; Upadhyay, 2023). The global scenario has been encouraging more and more industries and service providers to consolidate new economic, social and environmental drivers that are capable of being managed, aiming to make the production processes more sustainable, and with that, keeping perpetuity in the organizations (Franciosi *et al.*, 2020).

The need for companies to become sustainable, from an economic, social, environmental and governance point of view has been growing through the years, and so did the need to encourage the development of new technologies, able to expand the management of externalities (impacts), enabling not only, for example, the removal of pollutants and the modifications of a determined degraded area (because they are visible to society), but also to expand and to engage the many stakeholders to have a systemic view of improvement opportunities in the risks produced in each process by the various actors that participate in the value generation for clients (Clément; Robinot; Trespeuch, 2022; Golroudbary; El Wali; Kraslawski, 2019). The establishment of more sustainable and lasting business procedure models reduces environmental and social impacts, bringing more value to the client (Bjørnbet *et al.*, 2021).

Organizations, in worldwide scope, have been getting more and more concerned about environmental management. The sustainability advancements in industries instigate to reflect and practice actions to reduce negative impacts related to economic, environmental, social and governance issues. Thus, since companies have commitment to preserve their image and stay sustainable (generating value, which gives them a competitive differential), it is important to engage the commitment assumed with the environmental preservation, showing it to suppliers, clients, investors, society and other stakeholders (Fontoura; Coelho, 2022; Lahti; Wincent; Parida, 2018; Yong *et al.*, 2022).

The process of materiality (identification of positive and negative impacts present in organizations), will help companies to be assertive when choosing the paths to be taken, in search of a management form that creates value for itself and other stakeholders. The agroindustry sector is very relevant for the environmental sustainability issue, because it is presumed that food production collaborates with about 25% of gas emissions in the whole world, generating considerable impacts relating to use of soil and water (Hoek *et al.*, 2021; Laca *et al.*, 2021). In this sense, the objective of the sustainability theme is to orient public and private sectors about economic, social, environmental and governance problems, and with it, provide an environmental management plan with a holistic view of the whole context, making companies stimulated to include naturally all these aspects in their processes management (Babbitt *et al.*, 2018).

Organizations which aim to perfect their productive processes through sustainable actions tend to apply eco-design, with focus on where the environmental factor is of strategic relevance. The benefits of this action are acquired by reducing the environmental impact and expenses during the product's life cycle. Environmental weighting must be considered throughout the product's use phase in order to improve its energetic capacity and extend its lifespan (Kamble *et al.*, 2021).

The government's actions to favor sustainability are dedicated basically to recycling and reuse of products, therefore, waste disposal is in the last stage of linear processes. However, the attention of researchers, organizations and governments is directed to the system of circular economy (Kamble *et al.*, 2021). Moreover, applied literature reveals that there is demand in the introduction and conception of the life cycle for

fabrication, providing the discovery of solutions for processing models and for more effective energy use (Morales-Mendoza *et al.*, 2018).

It is visible that sustainability has acquired a prominent place in regards to debates about natural resources and energy sources, the connection between the environment and humans and between economic evolution and global ecology. This way, preservation and a better selection of the theme of materials is the solution for scarcity of natural resources, which aims to identify potential impacts that organizations make and to know how to monitor them through effective management; thereby, we will give conditions so that future generations can also utilize these same materials; this being the principle of sustainable development (de Melo *et al.*, 2022).

The technique which associates the themes of eco-design and Life Cycle Assessment (LCA) aims at quantitative analysis and advancing product sustainability in the process stages. A set of procedures is applied during the productive processes, aiming to quantify the life cycle's inventory that is being structured. It identifies the impacts generated in each stage of the productive processes, and thus, it becomes possible to monitor the most adverse impacts through the product development (Santolaya *et al.*, 2019).

Studies present coherence relating sustainability and tools, in which both topics can be applied together, having favorable impact on the operations (Farias *et al.*, 2019). Due to issues regarding environmental impact, companies have done modifications in their activities in order to comply with legal requirements, and so, be able to meet consumer demands for sustainable products (Kaswan; Rathi, 2019).

Researches show that tools, such as the LCA, help to favor eco-design, obtaining changes in management and improvement opportunities assessments (Pereira *et al.*, 2020). Furthermore, eco-design aims to find equality between environmental, economical, technical and social matters, evaluating and selecting elements from the products (Chun *et al.*, 2018).

This tool aims to expand the effectiveness and determine ecological alternatives for points related to operation requirements and investments, as for example, raw material, water, energy and further outputs implied in production procedures, such as waste water, solid waste and emissions (Iñarra *et al.*, 2022). The objective of eco-design is to reduce environmental impact during the product's life cycle, increase its use, and provide more life cycles through, for example, the sharing and reuse of materials and energy (Aguiar *et al.*, 2021).

Eco-design has the objective of improving environmental behavior through environmental weighting in every phase of the execution of processes and products (Kurdve; Hildenbrand; Jönsson, 2018). Based on the intention of reducing environmental impacts produced by their business, many industries have employed redesign in their procedures in order to become perennial in the market in which they operate, and so, become sustainable (Ramos *et al.*, 2018). The same can be elaborated with the help of softwares (tools and methods), for example, those regarding the principle of life cycle of the process and/or product (Manzardo *et al.*, 2021). The tools are used as support to analyze raw material reduction and map the

processes in which occurs elevated consumption of materials, water and energy, and so identify which activities cause more impacts (Fresner; Krenn, 2018).

This paper aims to identify and analyze the relation between the themes of sustainability and eco-design in productive processes, connecting them with environmental management tools.

2. MATERIAL AND METHODS

Aiming to make a critical analysis about the addressed topics and to answer the research questions: “What relation exists between the topics of sustainability and eco-design in productive processes?” and “Which environmental management tools are related to these topics?”, a Systematic Literature Review (SLR) was made. Known as an important research model, SLR seeks to contribute to establishing and elaborating practices supported by fundamentals, helping in the identification of gaps, consensus and problematics, and aiding the researcher to make new discoveries (Brizola; Fantin, 2016).

Therefore, this study has the objective to assess articles that have been developed about the topics: sustainability and eco-design in industrial production processes; identifying the most used environmental management tools. To better organize the research data, the methodology was organized in the following stages:

- Stage 1 – Identifying the research bases: The chosen journal databases were Scopus, Science Direct and Web of Science, due to their good conceptualization in the academic field and their volume of published articles associated with the research topics.

- Stage 2 – Research period: The research was made in February of 2023; being considered only documents published in the years of 2010 through 2022, since before this timeframe the quantity of articles on this topic is scarce.

- Stage 3 – Criteria for choosing search terms: In the article search were used the keywords “Tools”, “Eco-design”, “Sustainability” and “Production process”. In the search field was used “Article title”, “Abstract” and “Keywords”, utilizing the Boolean operator AND. The type of selected document was “Article”. Table 1 shows the documents found in the searched databases.

The criterion for the search of articles is related to the keywords, in which it was sought to extract documents pertinent to sustainability and productive processes. 13 articles in the Scopus database were found, 296 articles in the Science Direct base and 1 article in the Web of Science base, totaling 310 articles. In the Science Direct base more documents were found, since it searches for sought words throughout the whole text.

In order to organize the found data in the SLR and systematize the study, the meta-analysis methodology PRISMA was used (Galvão; Pansani; Harrad, 2015). Through this method it was possible to make the quantitative treatment of the documents, performing a flowchart with four stages. Figure 1 presents a graphic summarizing the developed stages in the sorting of analyzed articles.

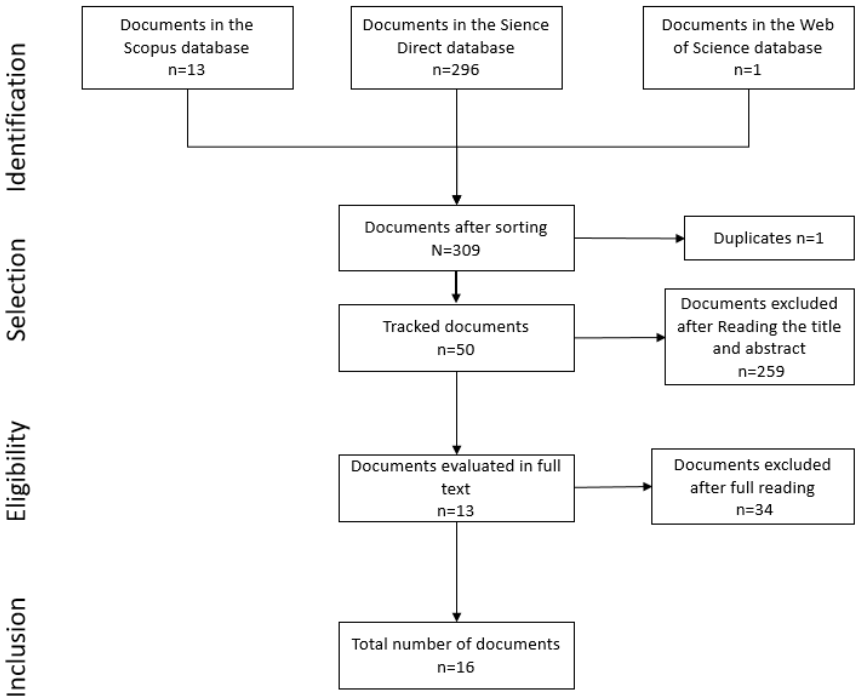
Table 1 – Number of documents found in the databases.

Databases (journal)	Keyword	Results
Scopus	"production process" and "tools" and "sustainability" and "eco-design"	13
Science Direct	"production process" and "tools" and "sustainability" and "eco-design"	296
Web of Science	"production process" and "tools" and "sustainability" and "eco-design"	1

Font: authors.

After selecting the articles for the research, the repeated documents were excluded, to the others can later have their titles and abstracts read in order to verify if they were related to the research objective. Lastly, a complete reading of the articles was made, analyzing which of them answered the study's questions, thus coming to the final number of sixteen articles.

Figure 1 – Quantitative analysis of the PRISMA model of research.



Font: authors.

The VOSviewer software was used in the qualitative analysis of the documents. This stage considered 310 documents found in the search performed in the databases. VOSviewer is a tool that aims to create maps based on previously treated data, assisting the researcher to analyze a determined topic. It also allows to identify the authors who publish the most in the field and their quantity of studies over the years (Van Eck; Waltman, 2011). For this, the following sequence was used:

1) Identification of articles about the topic in the Scopus, Science Direct and Web of Science databases, already excluding duplicate documents, resulting in a total of 309 articles.

2) Grouping the terms based on found data, unifying similar ones and keywords in plural, as for example: “eco-design” and “ecodesign”; and “environmental impact” and “environmental impacts”.

3) Definition of methodology: to choose the occurrence of words, the counting was defined to be made three times in order to better observe the graphic in the software.

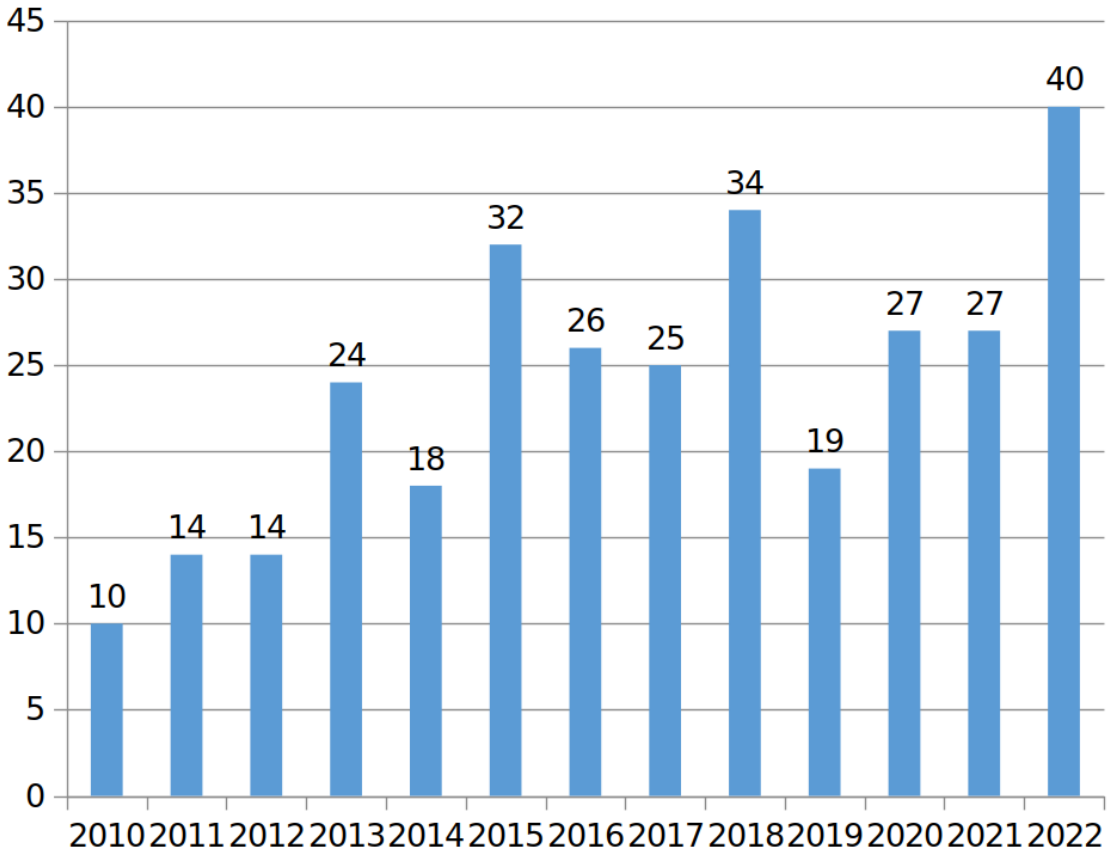
4) To visualize the results, two graphics were generated, in which the first one shows the clusters through the occurrence of keywords and the second shows which words are being studied more per period.

3. RESULTS AND DISCUSSION

3.1. SEARCH FOR ARTICLES IN THE JOURNALS

A total of 310 articles were found in the Scopus, Science Direct and Web of Science databases, encompassing about 1.016 authors and co-authors. Figure 2 shows the papers’ publications in the last thirteen years, taking into account the period between 2010 and 2022.

Figure 2 - Quantity of publications in the Scopus, Science Direct and Web of Science databases per period.



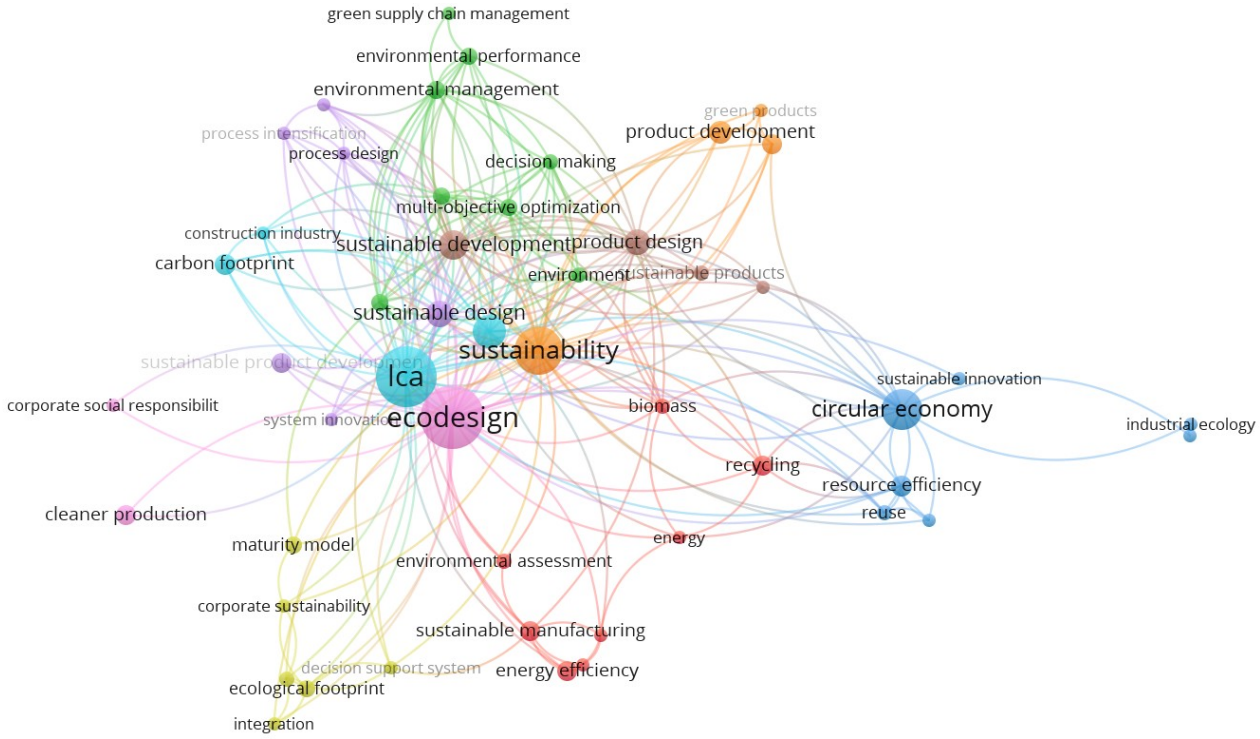
Font: authors.

The period of 2010 and 2011 were the first years when there was a considerable quantity of studies on the research topic, totalizing 24 articles. In the timeframe of 2012 through 2013 it is observed that there was a publication increase from 14 to 24 articles, meaning a 71,43 % increase from a year to the next. During the time between 2014 to 2015 it is possible to verify that there was an increase in the publication quantity of articles from 18 to 32 in the addressed topic, representing in this time interval 77,77 % of more published works. In the period of 2016 through 2017 it is noted that the publication number about the topic is practically maintained, from 26 to 24 articles. In the timeframe between 2018 and 2019 it can be observed that a reduction in documents published occurred from 34 to 19, representing 44,12% less publications from a year to the next. And lastly, in the period from 2020 to 2022 it is initially noticed that the publication number was stable, with 26 publications in 2020 and 27 in 2021, ending with an increase of quantity in 2022 with 40 articles published, this being the year with the most published studies about the related topic.

3.2. ANALYSIS IN THE VOSVIEWER SOFTWARE

Every article found in the journal databases were analyzed in the VOSviewer software in order to verify recurrence of words at least three times, and so generate clusters with the most quoted words in the selected documents for the study (Figure 3).

Figure 3 – Clusters generated through recurrence of words.



Font: authors.

As it can be verified in Figure 3, through the selected articles four clusters of greater relevance were generated, those being: sustainability, eco-design, LCA and circular economy. These topics are directly related as they seek to discuss improvement in

sustainability, whether in the production and management of a product, service or system.

The red cluster demonstrates the use of environmental impact assessment, in which it is sought energetic efficiency, reducing its consumption in processes of sustainable product manufacturing, through raw material recycling. The green cluster demonstrates the use of environmental management to have better decision-making in procedures regarding environmental aspects through a green supply chain, thus improving its environmental performance in products. The dark blue cluster brings us to the present topic, that is the circular economy, in which the objective is to bring sustainable innovation through reuse within production processes, seeking maximum efficiency of available resources.

The yellow cluster illustrates the search for the ecological footprint in processes, in which an environmental risk assessment is carried out to obtain a decision support system, aiming to practice sustainability within the organization. The purple cluster brings the theme of sustainable design into the process, through the development of sustainable products from the project to its final phase, putting into practice the intensification of processes, and thus innovating its sustainable systems. The light blue cluster presents the use of the LCA tool in construction industries, with the aim of reducing the environmental impact generated, through reduction of carbon use in its procedures, avoiding environmental pollution.

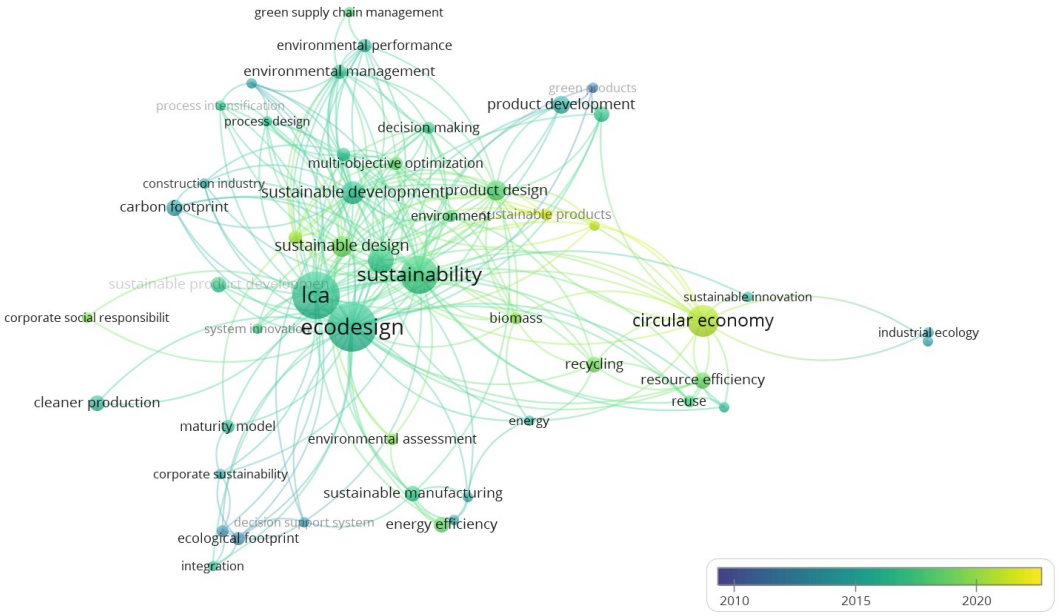
The orange cluster showcases innovation in the development of green products, using mainly the matter of recycling, in search of sustainability in production processes. The brown cluster brings sustainable development of processes related to industry 4.0, which aims to create sustainable products, achieving this through changing product design in pursuit of sustainability. The pink cluster illustrates the concerns that companies have with corporate social responsibility, and to achieve this improvement, cleaner production and eco-design are being applied in their processes and products in favor of environmental sustainability.

By prioritizing sustainability in the processes, it is possible to think about aspects of eco-design and product life cycle, observing environmental impacts at all stages of production. LCA makes the creation of a database possible, which can facilitate decision-making, leading companies to obtain environmental, economic and social advantages, mainly related to recycling materials and reduction of raw material use (Bonoli; Zanni; Serrano-Bernardo, 2021).

Figure 4 highlights the evolution of the topics over the years, enabling the identification of the most current topics that are being discussed and published. Through this research it can be observed that the most current topics are circular economy. The circular economy is employed for material reuse in production processes, increasing products' lifespan, aiming to reduce or eliminate waste, generating economic advantages for the company (Ghisellini; Ripa; Ulgiati, 2018).

Other topics such as industry 4.0, sustainable products and environmental sustainability have also been mentioned recently, although still infrequently.

Figure 4 – Relevancy of words by period.



Font: authors.

3.3. ANALYSIS OF DOCUMENTS BASED ON THE SELECTED

From the analysis carried out on the selected documents using the PRISMA methodology, 16 were validated as eligible. They were analyzed and discussed with the purpose of understanding the relationships between the topics of sustainability and eco-design in production processes. Table 2 highlights the title, objective, authors and year of publication of the chosen documents.

Table 2 – Articles selected for research discussion.

Title	Objective	Author/Date
Redesign of a component based on eco-design practices: environmental impact and cost reduction achievements	Identify how eco-design is applied in the redesign of a footwear item to reduce environmental impact and at the same time minimize production costs.	(Borchardt *et al.*, 2011)
Eco-design maturity model: a management framework to support eco-design implementation into manufacturing companies	Present an eco-design implementation model based on the development of a company's products, aiming to suit practices and improving processes.	(Pigosso; Rozenfeld; Mcaloone, 2013)
Key elements for implementing a strategic sustainability perspective in the product innovation process	Demonstrate key elements for the successful implementation of a sustainability strategy in the early stages of the product innovation process.	(Hallstedt; Thompson; Lindahl, 2013)

Eco-design for Production Plants	Develop a methodology for the development of energy-efficient production plants, with the objective of minimizing energy consumption and carbon dioxide emissions.	(Stoffels; Vielhaber, 2014)
Empirical study on integration of environmental aspects into product development: processes, requirements and the use of tools in vehicle manufacturing companies in Sweden	Obtain insights into how Design for Environment (DfE) is organized at four vehicle manufacturing companies in Sweden, indicating the processes of identification and integration of environmental aspects in product development, the type of environmental requirements considered and the use of different types of DfE tools.	(Poulikidou; Bj€Orklund; Tyskeng, 2014)
Success factors for environmentally sustainable product innovation: a systematic literature review	Aggregate existing research and findings from various studies on innovation of environmentally sustainable product through published literature on the topic, and identify critical factors for success that drive the increase of product innovation developed in this new logic of production and consumption.	(de Medeiros; Ribeiro; Cortimiglia, 2014)
An approach to Sustainable Product Lifecycle Management (Green PLM)	Describe a perspective on the green product life cycle involving the main phases: project, manufacture and service, including usability and renewal, suggesting a framework for sustainable product development that takes into account its entire life cycle.	(Vila *et al.*, 2015)
Fostering selection of sustainable manufacturing technologies e a case study involving product design, supply chain and life cycle performance	Compare a technology for manufacturing thermoplastic sandwich structures with three-dimensional contours with two technologies commonly used to produce similar components based on life cycle.	(Ribeiro *et al.*, 2016)
Integration of environmental aspects into R&D inter-organizational projects management: application of a life cycle-based method to the development of innovative windows	Analyze the structure of a project of solar energy harvesting with multifunctional glass polymer windows, which aimed to design innovative smart windows with glazing and frames composed of glass and polymer, with the objective of identifying strong and weak points for the integration of environmental and LCA aspects.	(Baldassarri *et al.*, 2016)
Review of eco-design methods and tools. Barriers and strategies for an effective implementation in industrial companies	Carry out a new literature review on the main eco-design methods and tools published in the literature in the last twenty years, seeking to understand the main obstacles that limit their real and effective implementation in industrial companies.	(Rossi; Germani; Zamagni, 2016)
Measuring the implementation of eco-design management practices: A review and consolidation of process-oriented performance indicators	Provide organizations with a set of process-oriented indicators to support and enhance eco-design implementation and management.	(Rodrigues; Pigosso; Mcaloone, 2017)

Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry	Develop a new checklist for Sustainable Product Development (CSPD) with the collaboration of designers and engineers to overcome the disadvantages of tools used in eco-design.	(Sch€Oggl; Baumgartner; Hofer, 2017)
A practical methodology to project the design of more sustainable products in the production stage	Obtaining improved products throughout their production stage through the application of a methodology, which consists of three distinct phases: sustainability assessment; product redesign; and comparing designs.	(Santolaya *et al.*, 2019)
Smart circular product design strategies towards eco-effective production systems: A lean eco-design industry 4.0 framework	Explore the relationship between lean eco-design and I4.0 strategies to design eco-efficient products based on a literature review.	(Dahmani *et al.*, 2021)
Achieving sustainable industrial ecosystems by design: A study of the ICT and electronics industry in Taiwan	Understanding the computer, communications and consumer electronics industries in Taiwan can move from a business as usual model to a more sustainable business through design.	(Suppipat; Hu, 2022)
Sustainability Failure Mode and Effects Analysis – A systematic literature review	Demonstrate that the FMEA is being increasingly modified in order to additionally align company decisions with ecological and social criteria.	(Von Ahsen; Petruschke; Frick, 2022)

Font: authors.

The study of Borchardt *et al*. (2011) has its main focus on eco-design, with the purpose of verifying the redesign of products in the footwear sector, analyzing the advantages and benefits related to the economic and environmental aspects of the company. The company investigated had a history of environmental concern, focused on developing innovative products and wanted to reduce costs in the production process. As a result of having employed eco-design and management system in its processes, the company managed to obtain economic gains of around 10%, and even so, it managed to reduce the use of raw materials and non-recycled materials. And in addition, it eliminated all use of toxic materials in the process.

The article Pigosso, Rozenfeld and Mcaloone (2013) emphasizes that, through the management and implementation of eco-design along with the use of tools such as PDCA and BPM (Business Process Management), it is possible to improve processes. In order to obtain better environmental gains, it is preferable to think about eco-design practices already in the product development phase, providing greater organization for the subsequent phases of the process. Thus enhancing environmental performance and reducing environmental impacts in the life cycle of products, always seeking continuous improvement in the procedures. The study highlights that there are issues that can be better explored such as: culture, hierarchy, organizational structure and company financial issues, since these aspects can influence the implementation of eco-design.

In Hallstedt, Thompson and Lindahl (2013) interviews were made in six companies with the purpose of improving their sustainable strategic developments, which were was carried out in four stages: search for favorable points to implement sustainability

and innovation strategies in company processes; verify challenges with the aim of producing the right products; carry out the production process correctly; and identify the methods and tools. Based on the assessment of the environmental impact of products, the study orients decision-making in their development stage, showing how to use the results obtained in the interviews in your process in search of more sustainable products, thus having an advantage over its competitors.

According to Stoffels and Vielhaber (2014), this study, through the use of tools, verifies the energy consumption of production. Eco-design was used with the objective of reducing the environmental consequences in the life cycle of goods. Through redesign it was possible to develop more ecological products that affect less the environment, using LCA aiming to compare the goods in the process and know what causes the most environmental impacts. By analyzing the inputs and outputs and increasing the energetic efficiency of the production plant, it is possible to reduce energy consumption. This research shows that the production plant can be viewed as a product which, seen as a whole, generates less possible environmental impacts, being able to use renewable energy. It was concluded that layout changes improve the quality of life cycles.

The study of Poulikidou, Björklund and Tyskeng (2014) was made in car factories in Sweden, concerning the environment and the final cost of the product. Data collection was carried out through interviews, in a qualitative way, with the objective of obtaining more effective projects related to the environment. From the companies in which the research was carried out, two demonstrated environmental requirements that should be followed; one stipulates environmental goals included in their planning, and the last one debates environmental improvements aiming to implement in the process. Based on this, it was possible to identify the importance of requirement implementations in the beginning of the planning. As a result, it was verified that the vehicle manufacturers have the objective of reducing environmental impacts, especially in the operation stage of the product, using tools such as Failure Mode and Effect Analysis (FMEA) and LCA, and obtaining useful suggestions for those in charge of companies, providing basic information about the items to be considered.

In de Medeiros, Ribeiro and Cortimiglia (2014) the issue of environmental responsibility in companies is discussed, unraveling that there are organizations that analyze the market first to know the acceptance or rejection of sustainable goods, and those which are concerned with the environmental aspect regardless of the market, because this matter becomes a competitive differential in relation to competitors. In Brazil, one of the difficulties to implement sustainable products is data collection, which is often not done in a proper way. Consumers play an essential role in the sustainability of companies, because they are the ones who select brands and the developed products, helping to build an ever-growing sustainable market. And industries have an important role in sustainability, in which they must maintain a culture, proactivity and management tied to environmental aspects for the success of sustainable development.

The article from Vila *et al*. (2015) addresses the life cycle of a green regarding the phases of the project, fabrication/service, usability and renewal. It is suggested a model which points the stages of a product's life cycle, demonstrating the use of

methods, tools and knowledge aiming to achieve sustainability. The procedures utilized are managed through eco-design, thus increasing efficiency in product production and a sustainable life cycle. The use of management tools of a product's life cycle is evident, tools which contribute to the organization of processes and stages of the cycle.

According to Ribeiro *et al*. (2016), the objective of this study was the fabrication of more sustainable bicycle frames, in which the LCA method was used, aiming to analyze technical, economic and environmental results, providing decision-making through indicators. It was possible to observe several parameters of the life cycle of the products, for example, production volume, cycle duration and labor cost. By reducing energy and material consumption, it was possible to carry out an environmental assessment, reducing impacts and enabling the reuse of 20% of materials. It was concluded that by redesigning the dimensions of the product it was possible to generate greater environmental and economic gains instead of consuming first-use materials.

Baldassarri *et al*. (2016), deals with environmental weighting in the design of innovative windows. In this project the LCEA tool was developed, which is used to execute an environmental assessment of life cycle. Five objectives were defined using the tool in the production of innovative windows: minimizing weight, increasing rigidity, attending environmental requirements, reducing stress and verifying the fabrication capacity. Based on this, a bespoke window design was developed, with the aim of reducing environmental impacts, since it possesses a smaller quantity of material, but with higher thermal capacity. In conclusion, this bespoke window design model met all the proposed objectives, satisfying environmental requirements during production, use phase and end of life.

In Rossi, Germani and Zamagni (2016), it is demonstrated tools applied to eco-design in industries through LCA, quantifying the environmental performances of the life cycle of products and processes. Several studies show that through the selection of materials it is possible to reduce environmental impacts, and that the use of eco-design enhances the items, thus making the company become more economically and environmentally competitive. To improve sustainability in companies, recovery and recycling are widely used, as well as the reduction of energy consumption. Through the application of eco-design, it is possible to face some obstacles, such as the time to apply the tools, the availability of financial resources, the application of the best tool, the amount of products and people committed to the environment.

According to Rodrigues, Pigosso and Mcaloone (2017), this research deals with the importance of eco-design, with the objective of improving sustainability in companies. In order to do this, indicators of eco-design management were used, which should reach the parameter of three or more specialists to evaluate them positively. The indicator is a form of managing the way sustainability is carried out, and not just the final result. By measuring the performance of processes, it is possible to achieve sustainable performance through continuous monitoring, and so, it is of paramount importance that companies develop environmental policies. Regarding sustainability, eco-design can measure, monitor and improve the procedures and product, and in this

way, companies can check their capabilities, determining what to keep and what to improve.

In Schöggl, Baumgartner and Hofer (2017), study, through the use of eco-design it was possible to bring a sustainable perspective in the development of items in the automotive sector. In order to collect data in the chosen company, research and workshops were carried out, and the LCA tool was used, with the aim of creating more sustainable products. A checklist for creating sustainable products was created, which resulted in exchange of information among the company's departments, encouraging the active participation of everyone in the making of the product. This way, it was possible to verify in a more forceful way the possible lack of sustainable aspects in the many production stages, especially in regard to decision-making at the beginning of the process.

In Santolaya *et al*. (2019), a quantitative methodology was used, that unites eco-design with information about sustainability of the item's life cycle in its fabrication. This research carried out a production inventory defining inputs and outputs, reaching indicators with the objective of measuring the sustainability of the process - in which it was pointed out the greatest impacts - and so putting eco-design in practice. The redesign of the product considered impact elements regarding sustainability. The article analyzes items such as use of energy, waste generation and production cost, thus making not only environmental benefits, but economic ones too. Aiming to reduce production of waste and increasing production, changes occurred in the choice of raw materials. With this study it was possible to reduce the use of energy in 51% and the loss of raw material in 13,2% after the redesign of the process, thus obtaining a lesser environmental impact.

According to Dahmani *et al*. (2022) it is demonstrated how eco-design has been stimulating companies to enhance their environmental performance, mainly reusing and recycling products in its process, giving it focus on sustainability. With its use, it becomes possible to reduce waste, increase product life cycle, reduce the use of raw material and energy, bringing long-term economic and sustainable benefits to the organization. It is important to emphasize that for the implementation of eco-design, suppliers and customers of the company must be involved, and so having success in its application.

According to Suppipat and Hu (2022), a survey was carried out with the twelve companies judged as the most ecological in the electronics area of Taiwan. The usage of eco-design collaborates with the reduction of environmental impact and in economic items of production. The tools adopted in the procedure with the objective of increasing sustainability fit in three groups: those for thinking of life cycle; those for thinking of design; and those of business models. Tools of the first group, such as LCA, are utilized for evaluation. Those of the second group aim to discover problems in the process and thus generate possibilities for innovation. The third group of tools are applied to the company's business, social and sustainability matters. This research enables companies to be aware of the life cycle of products, saving energy and reducing the use of materials by the means of recycling and reuse, and thus reducing waste generated.

In the article of Von Ahsen, Petruschke and Frick (2022), it is discussed how the FMEA tool can be used for sustainable development in products and procedures. This tool is easy to comprehend and execute, as it is widely applied in quality issues, thus making its adaptation can facilitate its insertion in sustainability. It is already used for the matter of sustainability in car manufacturers, because of ecological factors about emissions resulting from its process. Furthermore, the tool can be employed in any type of industry, generating environmental benefits, and being able to be analyzed in particular. A great advantage of FMEA is that it can be applied along with LCA in order to assess environmental risks of products, thus emphasizing that the tool can be used in issues related to sustainability management.

Table 3 shows the relation between eco-design and, highlighting which tools were used and the sustainable impact obtained in the articles.

Table 3 – Relation between eco-design and sustainability in the articles.

Author/Date	**Relation between eco-design and sustainability**	
	Tools/Techniques	**Sustainable Impact**
(Borchardt *et al.*, 2011)	Eco-design + Management systems	• Cost reduction • Reduction of non-recyclable materials • Raw material reduction
(Pigosso; Rozenfeld; Mcaloone, 2013)	PDCA cycle + Eco-design + BPM (Business process management)	• Improvements in processes • Reduction in environmental impacts in the life cycle of products • Environmental gain
(Hallstedt; Thompson; Lindahl, 2013)	Environmental Impact Assessment (EIA) + Life Cycle Analysis + Inovation	• Development of more sustainable products • Improvements in processes
(Stoffels; Vielhaber, 2014)	Eco-design + Life Cycle Analysis + Layout changes	• Reduction in environmental impacts in the life cycle of products • Reduction of energy consumption
(Poulikidou; Björklund; Tyskeng, 2014)	Life Cycle Analysis + FMEA (Failure Mode and Effect Analysis)	• Reduction of environmental impacts • Improvements in the life cycle of products
(De Medeiros; Ribeiro; Cortimiglia, 2014)	No tools	• Implementation of sustainable products • Material recycling • Improvements in the lifespan of products
(Vila *et al.*, 2015)	Life Cycle Analysis + PLM (Product Lifecycle Management) + Eco-design	• Effectiveness in production of more sustainable products • Organization of processes

(Ribeiro *et al.*, 2016)	Life Cycle Analysis + Indicators	• Assistance in decision-making • Reduction in energy and material use • Environmental and economic gain
(Baldassarri *et al.*, 2016)	Inovation + LCEA	• Reduction of environmental impacts • Reduction of raw material
(Rossi; Germani; Zamagni, 2016)	Eco-design + Life Cycle Analysis	• Reduction of energy consumption • Adoption of material recovery and recycling practices
(Rodrigues; Pigosso; Mcaloone, 2017)	Eco-design + Indicators + Continuous monitoring	• Improvement of processes • Measuring and monitoring of sustainable products
(Schöggl; Baumgartner; Hofer, 2017)	Eco-design + Life Cycle Analysis	• Identification of failures in decision-making • Identification of lack of sustainable aspects in the productive process
(Santolaya *et al.*, 2019)	Life Cycle Analysis + Inventory + Definition of inputs and outputs	• Reduction of energy consumption • Reduction of waste generation • Reduction of production cost • Reduction of raw material use
(Dahmani *et al.*, 2022)	Eco-design	• Reduction of wastes in the process • Increase of product's life cycle • Reduction of raw material and energy use • Involvement of suppliers and customers
(Suppipat; Hu, 2022)	Life Cycle Analysis + Design + Business Model	• Energy saving • Reduction of natural resources use • Recycling and reuse of materials • Reduction of waste generation
(Von Ahsen; Petruschke; Frick, 2022)	FMEA + Life Cycle Analysis	• Improvement of sustainability of products • Improvement of processes

Font: authors.

Based on the articles studied, it is possible to verify that tools and techniques applied to the production process are very important to improve the sustainability of the company, thereby reducing environmental impacts. Eco-design is also of great importance for the processes and the products' sustainability, in which it is identified their possible failures and gains, in order to make improvements.

The use of the LCA is more applied in the environmental management area, for being able to identify and evaluate environmental impacts, through the inventories carried out. Another important point is that it can be used together with other tools, not only in the environmental area, but in other ones as well. With this, it is possible to raise the standards for sustainability, reducing the impacts generated in the production process and in addition, it is possible to improve the layout of the organization,

reducing failures and waste and achieving economic, social and environmental gains for all the interested parties.

It is noted in the articles studied for this research the scarcity of the use of action plans related to sustainability in companies, this is due to the fact that most industries focus on an economic objective first and then on the environmental factor. With the use of the action plan aimed at making decisions related to sustainability and eco-design of the process, it is possible to manage tasks that need to be improved in the company, thus obtaining a good economic results.

4. CONCLUSIONS

Some companies have been using the sustainability issue as differentiation advertising in the market, trying to attract customers to more sustainable products, and so making their processes more efficient and generating less impact on society and the environment. From this research, it was found that the use of eco-design associated with sustainability brings results such as: reduction of waste in the process, reduction in the use of raw materials and energy, process improvement, measurement and monitoring of sustainable products and cost reduction.

Through this study, it was observed that the application of tools in the production process in search of sustainability in companies generates not only environmental benefits, but also social, economic and governance ones. The tools that are most used in production processes related to sustainability and eco-design according to the research are: PDCA cycle, Business Process Management, Life Cycle Assessment, Failure Modes and Effects Analysis and Business Model.

It is also evident that through the use of LCA and eco-design it is possible to improve the lifespan of goods cycle, making them more sustainable. This happens by reducing the use of raw materials, reducing waste generation and mainly reducing energy consumption, both in the production of a new product and in the recycling of materials. Another important point is that it was possible to visualize existing improvement opportunities within the process, thereby avoiding waste and consequently reducing the company's environmental impacts.

It is important to point out that there are many materials and theoretical references for the application of tools in processes, which aim for a path towards full sustainability, and that many have already been applied with positive results regarding environmental, social, economic and governance issues. Through the qualification and development of teams, it becomes possible to improve topics such as: sustainability, eco-design, management tools and production process. In this way, organizations generate added value for themselves and their image that will be perceived by their customers, which will differentiate them in relation to their competitors, as they are increasingly paving a road of no return for the EESG (Economic, Environmental, Social and Governance), that must be improved by everyone.

Acknowledgments: The present article was developed with the support of Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financing Code 002. The authors also thank the National Council for Scientific and Technological

Development (CNPq), Brazil (grant 303934/2019-0) and Fapergs, for financial support, to UNISC, and to the Postgraduate Program in Environmental Technology.

5. REFERENCES

AGUIAR, M. F. *et al.* Circular product design: strategies, challenges and relationships with new product development. **Management of Environmental Quality: An International Journal**, v. 33, n. 2, p. 300-329, 2021.

BABBITT, C. W. *et al.* Closing the loop on circular economy research: From theory to practice and back again. **Resources, Conservation and Recycling**, v. 135, p. 1-2, 2018.

BALDASSARRI, C. *et al.* Integration of environmental aspects into R&D inter-organizational projects management: application of a life cycle-based method to the development of innovative windows. **Journal of Cleaner Production**, v. 112, p. 3388-3401, 2016.

BJØRNBET, M. M. *et al*. Circular economy in manufacturing companies: A review of case study literature. **Journal of Cleaner Production**, v. 294, p. 126268, 2021.

BONOLI, A.; ZANNI, S.; SERRANO-BERNARDO, F. Sustainability in building and construction within the framework of circular cities and european new green deal. The contribution of concrete recycling. **Sustainability**, v. 13, n. 4, p. 2139, 2021.

BORCHARDT, M. *et al*. Redesign of a component based on ecodesign practices: environmental impact and cost reduction achievements. **Journal of Cleaner Production**, v. 19, n. 1, p. 49-57, 2011.

BRIZOLA, J.; FANTIN, N. Revisão da literatura e revisão sistemática da literatura. **Revista de Educação do Vale do Arinos-RELVA**, v. 3, n. 2, p. 23-39, 2016.

CASNER, D.; LIVOTOV, P.; SILVA, P. K. D. TRIZ-based approach for process intensification and problem solving in process engineering: concepts and research agenda. **Advances and Impacts of the Theory of Inventive Problem Solving**, p. 217-229, 2018.

CHUN, Y.-Y. *et al.* Identifying key components of products based on consumer-and producer-oriented ecodesign indices considering environmental impacts, costs, and utility value. **Journal of cleaner production**, v. 198, p. 1031-1043, 2018.

CLÉMENT, A.; ROBINOT, É.; TRESPEUCH, L. Improving ESG scores with sustainability concepts. **Sustainability**, v. 14, n. 20, p. 13154, 2022.

DAHMANI, N. *et al.* Integrating lean design and eco-design to improve product design: From literature review to an operational framework. **Energy & Environment**, v. 33, n. 1, p. 189-219, 2022.

DE MEDEIROS, J. F.; RIBEIRO, J. L. D.; CORTIMIGLIA, M. N. Success factors for environmentally sustainable product innovation: a systematic literature review. **Journal of Cleaner Production**, v. 65, p. 76-86, 2014.

DE MELLO SANTOS, V. H. *et al*. Towards a green industry through cleaner production development. **Environmental Science and Pollution Research**, p. 1-22, 2022.

DE MELO, T. A. C. *et al.* Circular economy public policies: a systematic literature review. **Procedia Computer Science**, v. 204, p. 652-662, 2022.

FARIAS, L. M. S. *et al.* Criteria and practices for lean and green performance assessment: Systematic review and conceptual framework. **Journal of Cleaner Production**, v. 218, p. 746-762, 2019.

FONTOURA, P.; COELHO, A. How to boost green innovation and performance through collaboration in the supply chain: Insights into a more sustainable economy. **Journal of Cleaner Production**, v. 359, p. 132005, 2022.

FRANCIOSI, C. *et al.* Measuring maintenance impacts on sustainability of manufacturing industries: from a systematic literature review to a framework proposal. **Journal of Cleaner Production**, v. 260, p. 121065, 2020.

FRESNER, J.; KRENN, C. Theoretical minimum consumption calculation as starting point for cleaner production option identification as a new approach to benchmarking. **Journal of Cleaner Production**, v. 172, p. 1946-1956, 2018.

GALVÃO, T. F.; PANSANI, T. D. S. A.; HARRAD, D. Principais itens para relatar Revisões sistemáticas e Meta-análises: A recomendação PRISMA. **Epidemiologia e Serviços de Saúde**, v. 24, p. 335-342, 2015.

GHISELLINI, P.; RIPA, M.; ULGIATI, S. Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. **Journal of Cleaner Production**, v. 178, p. 618-643, 2018.

GOLROUDBARY, S. R.; EL WALI, M.; KRASLAWSKI, A. Environmental sustainability of phosphorus recycling from wastewater, manure and solid wastes. **Science of The Total Environment**, v. 672, p. 515-524, 2019.

HALLSTEDT, S. I.; THOMPSON, A. W.; LINDAHL, P. Key elements for implementing a strategic sustainability perspective in the product innovation process. **Journal of Cleaner Production**, v. 51, p. 277-288, 2013.

HOEK, A. C. *et al.* Towards environmentally sustainable food systems: decision-making factors in sustainable food production and consumption. **Sustainable Production and Consumption**, v. 26, p. 610-626, 2021.

IÑARRA, B. *et al.* Ecodesign of new circular economy scheme for Brewer's side streams. **Sustainable Chemistry and Pharmacy**, v. 28, p. 100727, 2022.

KAMBLE, S. S. *et al.* A large multi-group decision-making technique for prioritizing the big data-driven circular economy practices in the automobile component manufacturing industry. **Technological Forecasting and Social Change**, v. 165, p. 120567, 2021.

KASWAN, M. S.; RATHI, R. Analysis and modeling the enablers of green lean six sigma implementation using interpretive structural modeling. **Journal of cleaner production**, v. 231, p. 1182-1191, 2019.

KURDVE, M.; HILDENBRAND, J.; JÖNSSON, C. Design for green lean building module production - Case study. **Procedia Manufacturing**, v. 25, p. 594-601, 2018.

LACA, A. *et al*. Assessment of the environmental impacts associated with vineyards and winemaking. A case study in mountain areas. **Environmental Science and Pollution Research**, v. 28, n. 1, p. 1204-1223, 2021.

LAHTI, T.; WINCENT, J.; PARIDA, V. A definition and theoretical review of the circular economy, value creation, and sustainable business models: where are we now and where should research move in the future? **Sustainability**, v. 10, n. 8, p. 2799, 2018.

MANZARDO, A. *et al.* Combination of product environmental footprint method and eco-design process according to ISO 14006: the case of an Italian vinery. **Science of The Total Environment**, v. 799, p. 149507, 2021.

MORALES-MENDOZA, L. F. *et al*. Coupling life cycle assessment with process simulation for ecodesign of chemical processes. **Environmental Progress & Sustainable Energy**, v. 37, n. 2, p. 777-796, mar. 2018.

PEREIRA, G. M. *et al.* Expert insights on successful multinational ecodesign projects: A guide for middle managers. **Journal of Cleaner Production**, v. 248, p. 119211, 2020.

PIGOSSO, D. C. A.; ROZENFELD, H.; MCALOONE, T. C. Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies. **Journal of Cleaner Production**, v. 59, p. 160-173, 2013.

POULIKIDOU, S.; BJÖRKLUND, A.; TYSKENG, S. Empirical study on integration of environmental aspects into product development: processes, requirements and the use of tools in vehicle manufacturing companies in Sweden. **Journal of Cleaner Production**, v. 81, p. 34-45, 2014.

RAMOS, A. R. *et al.* A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil. **Journal of cleaner production**, 177, p. 218-231, 2018.

RIBEIRO, I. *et al.* Fostering selection of sustainable manufacturing technologies – a case study involving product design, supply chain and life cycle performance. **Journal of Cleaner Production**, v. 112, p. 3306-3319, 2016.

RODRIGUES, V. P.; PIGOSSO, D. C. A.; MCALOONE, T. C. Measuring the implementation of ecodesign management practices: A review and consolidation of process-oriented performance indicators. **Journal of Cleaner Production**, v. 156, p. 293-309, 2017.

ROSSI, M.; GERMANI, M.; ZAMAGNI, A. Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies. **Journal of Cleaner Production**, v. 129, p. 361-373, 2016.

SAHOO, S.; KUMAR, A.; UPADHYAY, A. How do green knowledge management and green technology innovation impact corporate environmental performance? Understanding the role of green knowledge acquisition. **Business Strategy and the Environment**, v. 32, n. 1, p. 551-569, 2023.

SANTOLAYA, J. L. *et al*. A practical methodology to project the design of more sustainable products in the production stage. **Research in Engineering Design**, v. 30, n. 4, p. 539-558, 2019.

SCHÖGGL, J.-P.; BAUMGARTNER, R. J.; HOFER, D. Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry. **Journal of Cleaner Production**, v. 140, p. 1602-1617, 2017.

STOFFELS, P.; VIELHABER, M. EcoDesign for production plants. **Procedia CIRP**, v. 21, p. 432-436, 2014.

SUPPIPAT, S.; HU, A. H. Achieving sustainable industrial ecosystems by design: a study of the ICT and electronics industry in Taiwan. **Journal of Cleaner Production**, v. 369, p. 133393, 2022.

VAN ECK, N. J.; WALTMAN, L. **VOSviewer manual**: manual for VOSviewer version, v. 1, 2011.

VILA, C. *et al*. An Approach to Sustainable Product Lifecycle Management (Green PLM). **Procedia Engineering**, v. 132, p. 585-592, 2015.

VON AHSEN, A.; PETRUSCHKE, L.; FRICK, N. Sustainability Failure Mode and Effects Analysis – A systematic literature review. **Journal of Cleaner Production**, v. 363, p. 132413, 2022.

YONG, J. Y. *et al*. Testing the stakeholder pressure, relative advantage, top management commitment and green human resource management linkage. **Corporate Social Responsibility and Environmental Management**, v. 29, n. 5, p. 1283-1299, 2022.

* Tradução para Língua Inglesa: Guilherme Lemões Iepsen[9]
https://orcid.org/0009-0008-0373-4364 http://lattes.cnpq.br/8970059223175244

** Revisão de Língua Inglesa: Carlos Alexandre Lutterbeck[10]
https://orcid.org/0000-0002-7709-7918 http://lattes.cnpq.br/3747695210156927

Submetido em: **23/10/2023**

Aceito em: **09/04/2024**

[9] E-mail: giepsen@mx2.unisc.br
[10] E-mail: carlosalexandre@unisc.br