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Lean and the circular economy: A systematic literature review

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Abstract: Lean is a well-renowned strategy for increasing the value of products by minimizing waste. The circular economy is a new paradigm designed to mitigate environmental problems in production activities. Considering both perspectives, this article aims to understand how the application of lean can support the achievement of the circular economy. In order to attain this goal, the research presents a systematic literature review using the Scopus and Web of Science databases. Notably, the literature on the theme is still at an exploratory stage, the vast majority of research consisting of case studies. The main lean tools identified in the research are 5S and value stream mapping. The main circular practices, with lean support, are the Rs and eco-design. The research proposes Circular Lean as a novel concept, one which merges some of the existing lean and circular economy principles. The main idea of this concept is the reutilization of material and energy, adding value and reducing waste within production processes and product life cycles.

Keywords: Lean, circular economy, circular lean, sustainability, sustainable development.

1. Introduction

At the beginning of 1949, one of the biggest companies in the automotive industry faced a crisis over a collapse in its sales. This crisis prompted Eiji Toyoda, a young engineer, to investigate the production processes applied by other companies in the sector, in order to discover new concepts that could be applied in his company. After analyzing the production processes used in one of Ford's plants, Toyada believed that the production system in his own company, Toyota, could be improved. Back in the city of Nagoya, Toyoda, together with Taiichi Ohno, developed the Toyota Production System, which was later popularized as Lean Manufacturing (Womack et al., 2004).

Today, it is not only production issues that receive the attention of companies; environmental problems have also become part of the agenda (Bonciu, 2014; Sartal et al., 2020). The world faces several issues within the environmental sphere, such as land degradation, pollution of natural systems and climate change, which are rooted in human activities such as production and consumption (UNEP, 2021). The circular economy (CE) is a concept that emerges to mitigate the environmental problems of production processes while generating economic gains and opportunities (Kirchherr et al., 2017; Suzanne, Absi and Borodin, 2020). The CE proposes an economy that is restorative and regenerative, in which waste should be seen as a resource, and efficiency should be achieved (Linder, 2017; Weissbrodt et al., 2020).

The operational management field is considered to be an important ally for the transition from a linear to a circular flow, due to its innovative capacity, its importance in production processes and the opportunities for waste and pollution mitigation (de Sousa Jabbour et al., 2019; Pigosso and McAloone, 2021; Suzanne et al., 2020). However, there are still some uncertainties related to how this transition should be operationalized (Rosa et al., 2019), and companies face numerous challenges in managing the process (van Loon and Van Wassenhove, 2020). Therefore, the identification of strategies and tools that can support companies in this transition is an important topic of investigation, and one from which the following research question emerges: *Is lean manufacturing a feasible strategy for supporting the transition from the linear to the circular flow?* In order to answer this question, the present research aims to understand the state of the art of the relationship between lean and the CE through a systematic literature review.

There are various common aspects that justify the integration of lean and the CE. Lean is an approach that aims to increase the value provided to customers (Sassanelli et al., 2019). The incorporation of CE thinking within lean could provide an important opportunity to generate more value through product life cycles. As identified by Veleva and Bodkin (2018), increasing product value is convergent with the CE, which is reinforced by the difficulty of competing on price. The main goal of the CE is "to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017, p. 224). Lean already has an approach aligned with this idea: green lean represents the notion of synergistically combining Lean concepts with the CE, because there is a consensus between them of the need to avoid waste and reduce energy costs (Abreu et al., 2017).

The relationship between these themes and some of the Sustainable Development Goals (SDG) promoted by the United Nations also highlight the importance of this paper. The SDG is a key instrument, helping to achieve economic growth, environmental protection and social equity in the short and long term (Griggs et al., 2013). Schroeder, Anggraeni and Weber (2019) have also indicated the strong relationship between CE and the SDG. Considering the integration of lean in the current research, the following SDGs can be highlighted: Industry, Innovation and Infrastructure (SDG9); Responsible Consumption and Production (SDG12); and Climate Action (SDG13). Considering the transdisciplinarity of the CE, other SDGs are also indirectly related to this research.

Following the introduction given above, this paper comprises: a brief theoretical overview of lean and the CE, in section (2), the research methods adopted, in section (3); the presentation of the results, in section (4), the discussions arising, in section (5) and, finally, the conclusions, in section (6).

2. Theoretical Background

2.1 Lean

Lean arose from the Toyota automotive company that, after an unsuccessful attempt to produce in large scale during a period of collapsing sales, faced the necessity of cutbacks. The company implemented techniques to make the production lean, eliminating reworking, waste and inventory (Womack et al., 2004).

Lean manufacturing is based on five main principles: (1) production flow, which is based on the analysis of the physical environment and on the changes that can be made in order

to improve the movement through processes; (2) organization, which is focused on the function of each worker, searching for improvement techniques at work and developing communication; (3) process control, which is the way to control, stabilize and improve industrial processes; (4) metrics, which is the use of indicators and statistics to measure company performance; and (5) logistics, which is based on planning mechanisms to manage material flow (Feld, 2000).

Lean, which is well known for continuous improvement, seeks to eliminate unnecessary operations and reduce waste as much as possible (Kurilova-Palisaitiene et al., 2018). According to Hines & Rich (1997), there are 7 types of waste from a lean manufacturing perspective: (1) overproduction, (2) waiting, (3) transport, (4) inappropriate processing, (5) unnecessary inventory, (6) unnecessary motion, and (7) defects. Some authors suggest that overproduction is the hardest to solve, as it can be hidden within the other six types of waste (Librelato, Lacerda, Rodrigues and Veit, 2014). The waste types also relate to one another, for example, overproduction tends to increase waiting, unnecessary inventory and defects.

One of the main features of lean is the adoption of a pull system, which is a production system that limits the amount of work in process in a system (Hopp and Spearman, 2004). Several other strategies and tools are applied by a company that aims to implement lean thinking, such as Kaizen; 5S; continuous improvement; Just in Time; and Value Stream Mapping (VSM) (Pettersen, 2009; Tortorella et al., 2017).

Waste minimization in lean manufacturing can be analyzed through sustainable practices, which seek to mitigate pollution emission and waste generation in manufacturing processes (Abreu, Alves and Moreira, 2017). The concept of lean green emerged from this context, integrating sustainable practices with the ideas of lean manufacturing, which lead to lower levels of pollution, reducing the marginal costs of activities related to pollution and encouraging managers to invest in waste reduction (Bhamu and Sangwan, 2014; King and Lenox, 2001; Yang et al., 2011). Lean green also aims to reduce pollution levels during production processes rather than treat them at the end-of-pipe (King amd Lenox, 2001).

The CE paradigm emerged within the sustainability context, one that can be beneficial in the context of lean (Hedlund et al., 2020; Kurdve and Bellgran, 2021; Kurilova-Palisaitiene et al., 2018). However, despite some studies analyzing the concepts of lean green and the CE together (Hedlund et al., 2020), it is not yet clear how lean manufacturing or even green lean are related to the CE. Circular business models with a lean approach should be seen as a

sustainable innovation strategy focused on offering a system of circular products and services with aggregated value to the client in an efficient way (Romero and Rossi, 2017).

2.2 The Circular Economy

The CE emerged as a new paradigm to respond to the environmental problems faced by current society. The CE can be conceptualized at three levels of analysis: (1) micro, related to products, companies and consumers; (2) meso, related to industrial eco parks and industrial symbiosis; and (3) macro, related to municipalities, regions and countries (Ghisellini et al., 2016; Kirchherr et al., 2017). Differently from the traditional practices of the "linear economy", which is characterized by extraction, transformation, consumption and discard, and not concerned with the pollution and waste generated in each of these steps, the CE presents the logic of minimizing environmental degradation, recovering material and energy as much as possible during the whole life cycle of products (Kirchherr et al., 2017; Sauvé et al., 2016).

The three levels of analysis presented (e.g. micro, meso and macro) have implications for the relationship between lean and CE. From a macro perspective, it is important to note that some regions of the planet are more mature in the implementation of CE practices and policies than others. China and Europe stand out from the rest of the world in this respect. In China, there has been a notable increase in awareness of the CE over time. This has translated into the implementation of broad and progressive recycling and production initiatives through CE concepts (Zhu et al., 2019). The European Union, which has a relatively long history of environmental policies and legislation, has started to adopt a more holistic approach with the emergence of the CE Directives developed in recent years (Hughes, 2017). As examples, there are the development of the "Towards a Circular Economy: A Zero Waste Programme for Europe", "Closing the Loop: An EU Action Plan for the Circular Economy", and the "Circular Economy Action Plan" (Serrano-Bedia and Perez-Perez, 2022). These policies integrate the mitigation of environmental issues, such as those related to waste generation, with economic opportunities related to innovation, entrepreneurship and job creation (Völker et al., 2020). These macro environments also support the development of the CE at the other levels.

At the micro level, the CE is analyzed in relation to products, companies and customers. The company aspect, which is more related to lean, can also be analyzed based on other aspects, such as: circular business models (Lewandowski, 2016), green human resources management (Jabbour et al., 2019), and in the operational management field (De Sousa Jabbour et al., 2019). The meso level, on the other hand, offers insights related to the supply chains and industrial

symbiosis of companies. As presented in the results and discussions sections of this paper, the topic is still little explored in the literature.

The CE is an umbrella concept related to several practices that can be implemented at all these levels (Kalmykova et al., 2018). In total, Lima et al. (2021) identified 53 practices that can be adopted in support of the CE. In making their analysis, the authors created 9 groups of these practices which represent well the coverage of the CE: (a) Design, (b) Servitization, (c) Corporate social responsibility, (d) Circular production, (e) The 6 Rs, (f) Resources, (g) Taxes, (h) Behavior, and (i) Closed-loop supply chain. An important aspect to consider in all these practices is that CE seeks a restorative and regenerative environment (Linder, 2017; Weissbrodt et al., 2020). Resources should be used for as long as possible, in a circular and efficient manner, in what Bocken et al. (2016) named, respectively, as slowing, closing and narrowing the loop. The authors point to the narrowing aspect with caution, as it can lead to an increase in productivity and, thus, result in overproduction and consumption.

3. Method

In order to achieve the research goals, the present study applied a systematic literature review following the recommendation proposed by Paul and Criado (2020). Due to the integration of the elements of both the bibliometric and structured literature review, the review presented in this present research can be considered “hybrid” (Paull and Criado, 2020). To operationalize the review, the study followed, with some adaptation, the steps used by other reviews that can also be considered “hybrid” (Lima et al., 2022; Mariano et al., 2015).

The first step involved choosing the databases used to locate the articles. In this paper the authors chose the Scopus and Web of Science (WoS) databases, considering that they offer a high number of qualified articles. Both databases were recommended by Paul and Criado (2020) and chosen by the review articles used as parameters for this review (Lima et al., 2022; Mariano et al., 2015).

The second step involved searching for the articles in the chosen databases. To do this, appropriate keywords were selected. It is the objective of this paper to analyze lean and the CE as a whole; that is, it is not of interest to analyze only practices and tools that can be related to these concepts in isolation, but to find a systemic relationship between them. Therefore, the keywords were restricted to “lean” and “circular economy”, connected with the Boolean operator “AND”. In order to confirm the validity of this strategy from a methodological perspective, the authors made a prior search in review papers that covered lean and the CE with

other concepts. Several studies that used this strategy were found (e.g. Benachio et al., 2020; Danese et al., 2018; Pagliosa et al., 2019; Suchek et al., 2021).

After applying the keywords to the titles, abstracts and keywords of the documents in the databases, the first search found 85 documents in Scopus and 74 in WoS. The removal of documents not written in English and that were not articles published in peer-reviewed journals, which is a procedure of the review articles used as reference (Lima et al., 2022; Mariano et al., 2015), resulted in 45 articles in Scopus and 54 in WoS. After removing the duplicate articles, the sample comprised 59 articles, which were then analyzed by the authors. Next, three of the authors independently read the titles, abstracts and keywords of the articles, in order to select those that matched the scope of the research. When there was disagreement about whether to approve specific articles, discussion amongst the authors ensued to reach a consensus. This procedure was adopted in order to mitigate biases during the screening process. As inclusion criteria, an article should consider both lean and the CE together; even if the article presented some other results, at least one of its objectives should be to analyze the relationship between lean and the CE. As exclusion criteria, articles that only superficially mentioned one of these concepts (e.g. using the concepts to contextualize the study) or that only considered some specific elements of the concepts, without integrating them with the general idea of the concept (e.g. only considering recycling or reverse logistics without integrating them in the CE context), were also excluded. This screening process resulted in 19 articles, which would then be fully read.

During the step in which the articles were read in their entirety, the authors used the content analysis approach to extract data, in order to codify and aggregate information. The following data were prioritized: (a) the method used in the research; (b) which strategies analyzed in the article were related to lean (the authors considered the lean strategies indicated by Pettersen (2009) and Tortorella et al. (2017)); (c) which strategies analyzed in the article were related to CE (the authors considered the CE practices identified by Lima et al. (2021)); and (d) the main results and contributions of the article in terms of the relationship between lean and CE. Two articles were removed due to a lack of access to the complete study - this represents a number smaller than for the other review papers identified in the literature (Lima and Mariano, 2020; Lima and Mariano, 2022) - and thus the final sample of articles to be analyzed in the review was 17 articles. The whole screening process is summarized in Figure 1.

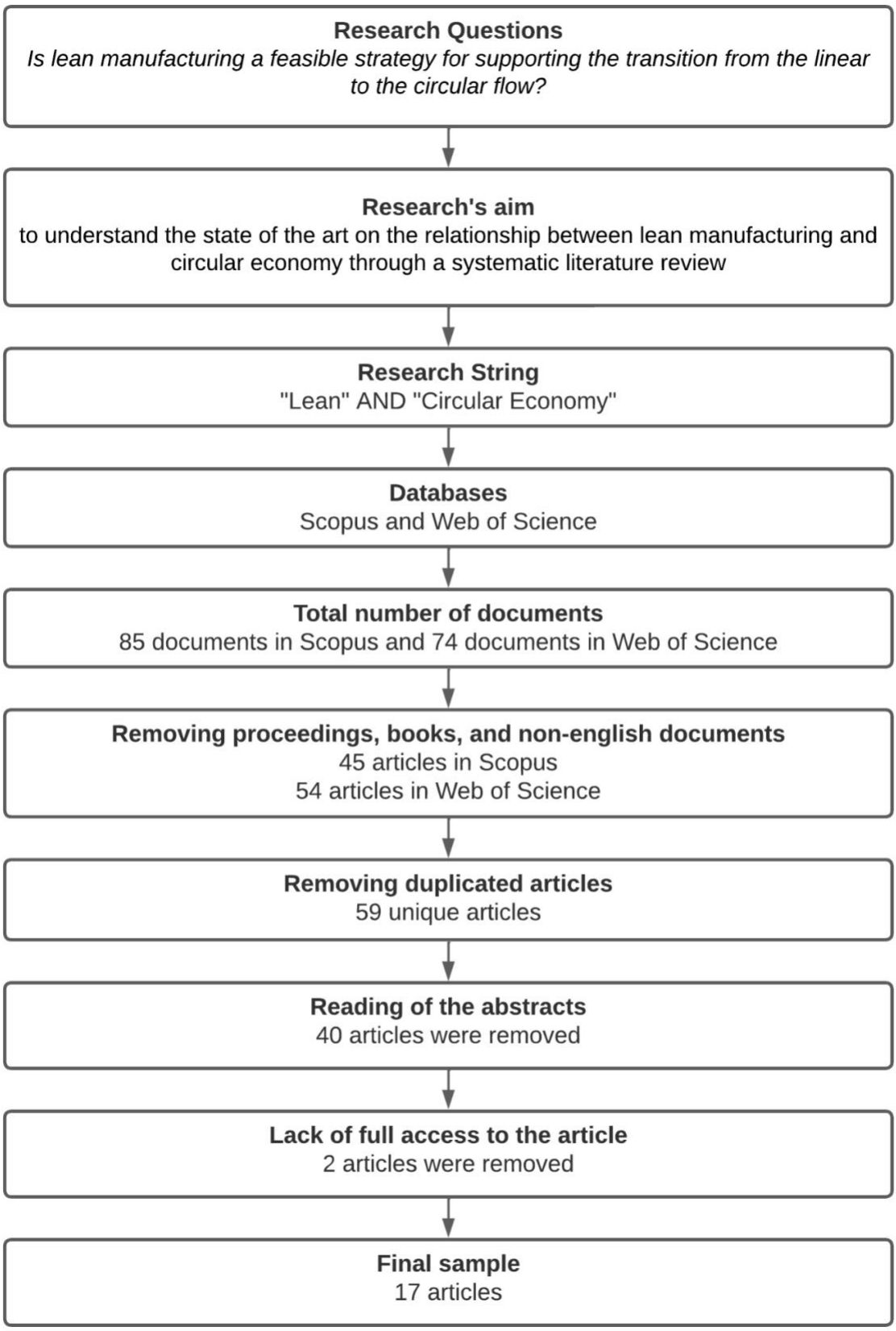

Figure 1 - Research flowchart

Although the final article sample is relatively small compared to other review papers in different areas, it is close to other recent reviews analyzing the CE with other concepts (e.g. Jesus and Jugend, 2021; Klein et al., 2020). A likely explanation for this is because the CE is an emergent topic, with a lot of research still to be done. Literature reviews based on new topics could be made (Torraco, 2005), which can support the development of the field by mapping how it develops and indicating research opportunities.

4. Results

The results section first presents the bibliometric analysis, considering the year and journal of publication, and then presents the content analysis, summarizing the main information taken from the papers.

4.1 Bibliometric analysis

Beginning with the bibliometric analysis (Figure 2), the first papers identified on the subject were published in 2018: the case study of Kurilova-Palisaitiene et al. (2018) analyzed how lean practices can support remanufacturing, and Minunno et al. (2018) published a study related to the transition to the CE in the prefabricated building sector supported by lean practices to reduce waste. In 2019 there were also two papers published. 2020 presented an increase of 100%, with four papers published.2021 presented the same growth rate of 100%, being the year with the highest number of papers published: eight. Only one paper was identified in 2022 (Lim et al., 2022), but the last search update was made in April 2022, thus it is expected that more papers will be published in this year.

Considering the journals where the articles were published (Table 1), the Journal of Cleaner Production stood out with seven articles, corresponding to 41.18% of the publications. Sustainable Production and Consumption, with two articles (11.76%), is the other journal with more than one publication. The other eight articles were published in different journals, including journals more related to environmental issues, such as Sustainability and Waste Management; operational management, International Journal of Quality and Service Sciences; and civil engineering, Buildings. These different journal types highlight how lean can be an important tool from an environmental perspective, and how the CE is an emergent concept in operational management.

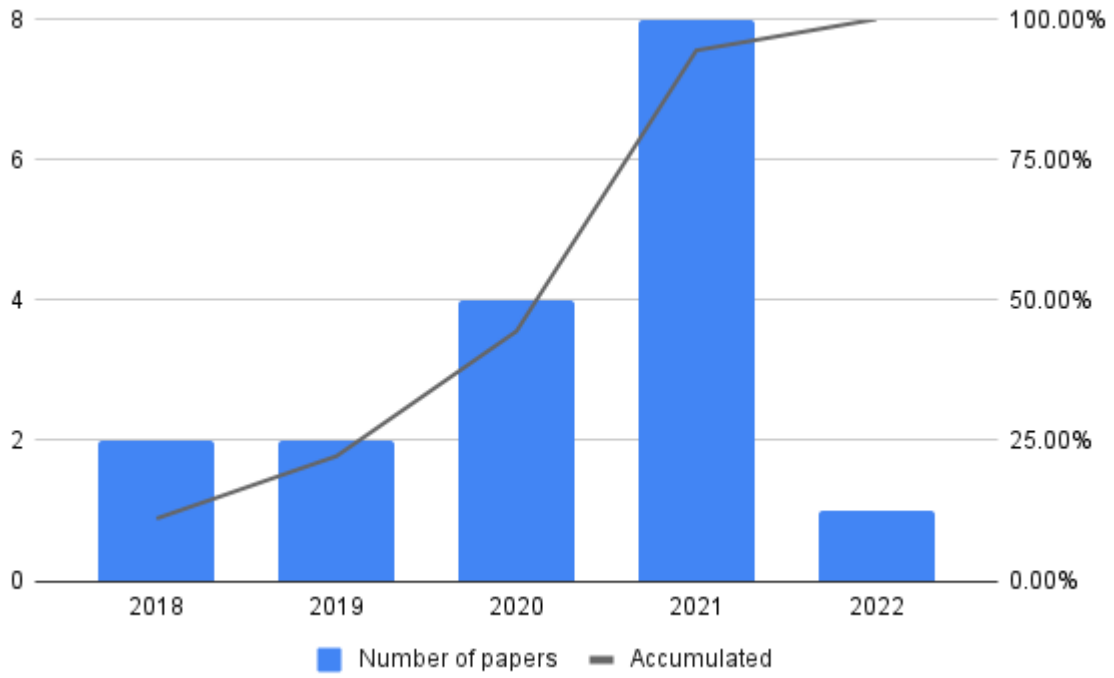

Figure 2 - Publications per year

Table 2 - Number of papers per journal

Journal	Number of papers	Percentage (%)
Journal of Cleaner Production	7	41.18
Sustainable Production and Consumption	2	11.76
Buildings	1	5.88
Business Strategy and the Environment	1	5.88
Cleaner Engineering and Technology	1	5.88
Entrepreneurship and Sustainability Issues	1	5.88
Environmental Challenges	1	5.88
International Journal of Quality and Service Sciences	1	5.88
Sustainability	1	5.88
Waste Management	1	5.88

4.2. Content analysis

Considering the research methods applied in the studies (Figure 3), there were one theoretical review, four literature reviews, nine case studies, and three surveys. The smaller number of surveys is an indication that the field is still in the earlier stages of research, where

more exploratory research, such as case studies, is expected. Quantitative research, such as surveys, is important for the generalization of results (Forza, 2002). The only theoretical paper (Ciliberto et al., 2021) suggests the integration of the CE, Lean and Industry 4.0 as a sustainable future for companies; the research indicates several operational and environmental benefits of this integration. None of the four literature reviews has the goal to analyze lean and the CE as their main research focus. Instead, they are research papers that analyze ways to foster the CE, lean being identified as one of the options (Dahmani et al., 2021; Polyakov et al., 2021); or are studies focusing on specific topics, such as the study that suggested lean as a support to achieving CE in the construction area (Minunno et al., 2018); and the research that analyzed case studies about green lean, located though a literature review, and pointed out how it converges on the goals of the CE (Kurdve and Bellgran, 2021). Therefore, these review articles did not affect the originality of the present research.

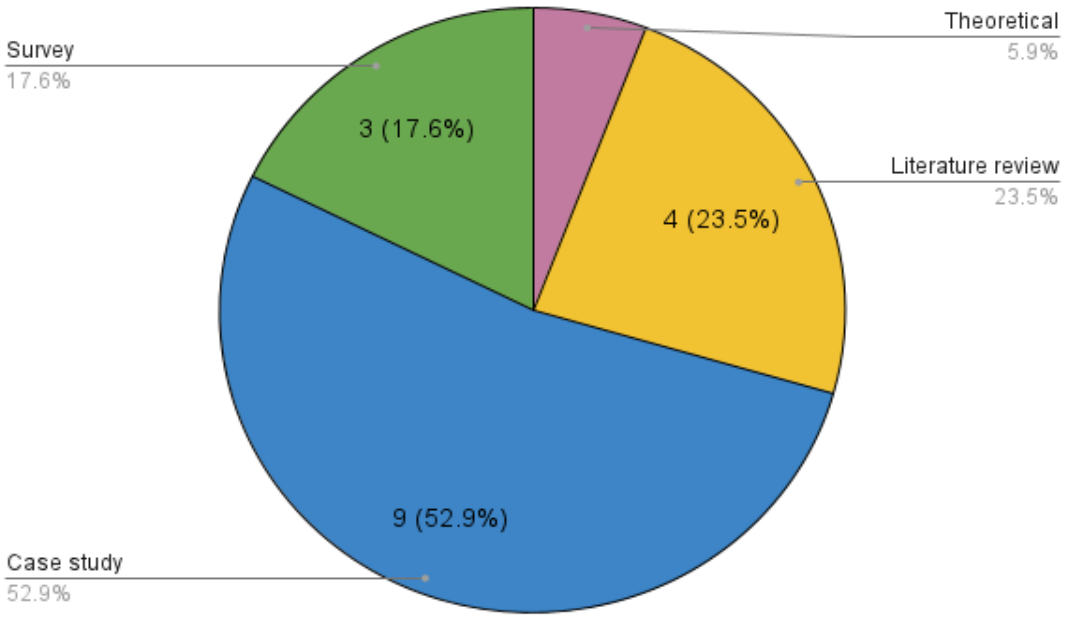

Figure 3 - Research methods applied

The higher number of case studies suggests the exploratory stage that the field is in. Different contexts were analyzed in these studies: small and medium-sized enterprises (Caldera et al., 2019), university laboratories (Gutierrez et al., 2020), remanufacturing (Kurilova-Palisaitiene et al., 2018), waste management (Marrucci et al., 2020), and resource consumption (Sartal et al., 2020). Some studies proposed indicators (Marquina et al., 2021) or management tools (Lim et al., 2022) to be tested as part of the case study. These papers are important examples, as they demonstrate the diversity of the application of lean and the CE.

Of the three survey studies, two (Akkalathama and Taghipourb, 2021; Piyathanavong et al., 2019) were carried out in Thailand, with questionnaires answered by managers in steel and manufacturing companies. The other study (Agyabeng-Mensah et al., 2021) also used questionnaires with manufacturing companies, but in Ghana. Agyabeng-Mensah et al. (2021) and Akkalathama and Taghipourb (2021) relied on the Structural Equation Model (SEM), while Piyathanavong et al. (2019) used descriptive and inferential statistics. The surveys found a positive relationship between lean and CE outcomes in the companies studied. However, they were not specific about which lean tools - or CE aspects - these companies were relying on. Clearly, much more research is needed, covering different countries and cultural backgrounds.

Several studies indicate that the application of lean within the CE context could generate economic and environmental benefits (Akkalathama and Taghipourb, 2021; Dahmani et al., 2021; Piyathanavong et al., 2019; Sartal, Ozceli and Rodríguez, 2020). Much of this relates to the reduction of emissions and materials, due to waste minimization (Caldera et al., 2019).

Hedlund et al. (2020) believe that VSM could be expanded in the CE perspective, which would be the consideration of value through the whole life cycle, reducing waste in all processes and increasing value perception. The CE is also important for expanding the perspective of product and process - as usually covered in lean - and for incorporating a system approach. In this case, a company would consider the importance of a whole-life approach, and not restrict the focus to the point at which a product is delivered to a customer (Schmitt et al., 2021).

Kurilova-Palisaitiene et al. (2018) suggested the importance of lean for increasing the operational efficiency of companies working with remanufacturing. One of the main positive outcomes would be lead time reduction, which is essential in CE environments: the lower the lead time to remanufacture, the lower the need to rely on traditional manufacturing to supply the demand for a given category of product. Remanufacturing reduces the necessity of using raw materials, one of the main aspects that the CE avoids, and sustains material closed loops. This is also an example of where screening the loop - making production processes more efficient - is also important.

Sartal et al. (2020) relied on 5S to improve water consumption and efficiency in a food company, while not affecting economic indicators. Gutierrez et al. (2020) also applied the 5S tool in an educational chemistry lab, which resulted in better waste management in the lab and acted as a first step in implementing other lean tools. The authors demonstrated that improving

integration between labs in order to share materials was a way to avoid waste. These results are important in that they demonstrate that a simple tool related to lean manufacturing, e.g. 5S, can support the circularity level of companies.

Another lean tool present in the literature is DMAIC (Define - Measure - Analyze - Improve), which can be adopted in environmental management tools to increase the mitigation of environmental pollution and waste generation (Marrucci et al., 2020). Lean and CE integration increases the possibility of mitigating environmental problems at moments when the lean approach for searching the core reason is not enough. For example, R hierarchy expands the set of options to be adopted (Kurdve and Bellgran, 2021).

Polyakov et al. (2021) emphasize the importance of lean in the implementation of CE principles. The authors recommend the creation of an information infrastructure (to increase the efficiency of production networks), digital platforms (to increase the interaction between producers and consumers), industrial parks, incubators for new industries, and investing in new innovative technologies. In this manner, lean is highlighted, together with individual and flexible manufacturing and distributed manufacturing, as one of the 3 pillars that can enable CE practices.

There are some barriers to the application of lean and CE practices. The literature reviewed in this paper indicates that lean and environmental management practices can be resource-demanding, which might be a higher challenge for SMEs (Agyabeng-Mensah et al., 2021). However, it is important to highlight that the application of lean can lead to cost reductions in the mid and long term (Caldera et al., 2019). Therefore, another important opportunity for investigation in the literature is possible common barriers related to lean and CE.

The literature mapping presented in Table 2 summarizes the main information taken from the papers analyzed, giving the research method, the main strategies analyzed considering lean (following the practices identified by Pettersen (2009) and Tortorella et al. (2017)), and the main practices related to the CE (following the practices identified by Lima et al. (2021)). A lot of the ideas presented in the literature mapping can be applied to any type of company aiming to increase their performance from a CE perspective. Other approaches, on the other hand, are more related to specific industries, such as remanufacturing (Kurilova-Palisaitiene et al., 2018) and the construction sector (Minunno et al., 2018).

Table 2 - Literature mapping

Paper	Research method	Lean related strategies	Circular Economy related strategies	Main contribution
Agyabeng-Mensah et al. (2021)	Survey	Lean manufacturing in general, lean product development, and zero waste	CE in general	The adoption of lean principles in manufacturing processes and in product development, as well as a zero waste focus, can support the achievement of CE indicators by a company
Akkalathama and Taghipourb (2021)	Survey	Lean production in general	CE in general	The adoption of lean production practices support the achievement of CE in companies.
Caldera et al. (2019)	Case study	5S, buffer level, capacity planning, cellular manufacturing, inventory reduction, just-in-time, Kaizen, lean culture, lean layout, lean supply chain, pull approach, total productive maintenance, value stream mapping, SMED, quality circle.	Corporate social responsibility, recycle, reduce, reuse, waste management	The application of lean tools and strategies can support the achievement of the circular economy at the firm level in small and medium-sized enterprises. The authors identify four enablers and six barriers for implementing sustainable business practices.
Ciliberto et al. (2021)	Theoretical	Green Lean, Kaizen, Just-in-Time, 5S, VSM	Reverse logistics, recycling, reuse, reduce, remanufacturing, waste management, energy and water optimization	A theoretical integration of the CE, Lean and Industry 4.0. The research points out several benefits of these three concepts.
Dahmani et al. (2021)	Literature review	Kaizen, lean design; lean thinking	Ecodesign, recycle, reduce, and reuse	The integration of lean ecodesign and industry 4.0 tools can improve product design in the CE context.
Gutierrez et al. (2020)	Case study	5S	Green procurement, redistribute, reduce, sharing, stewardship waste management	5S is an effective tool to start implementing lean in educational chemistry labs. Waste management practices and working-safety improved. The goal is to be able to share resources with other labs to avoid waste.

Paper	Research method	Lean related strategies	Circular Economy related strategies	Main contribution
Hedlund et al. (2020)	Case study	Value Stream Mapping	Recycle, reduce, refurbishment, remanufacturing, reuse, and waste management	The study proposes the expansion of the value stream mapping with CE concepts. Companies should consider value in their product, even during consumer use, by incorporating R strategies.
Kurilova-Palisaitiene et al. (2018)	Case study	Continuous flow, cross-training and learning through problem solving, factory layout, kanban, standard operation	Remanufacturing	Analyze how lean manufacturing can support the reduction of lead time in remanufacturing processes.
Kurdve and Bellgran (2021)	Literature review	5S, green lean, green value stream mapping, kanban	Waste hierarchy (Eliminate use, reduce, reuse material recycling, energy recovery, landfill)	The implementation of green lean tools and strategies can support the achievement of CE.
Lim et al. (2022)	Case study	Green Lean, Kaizen	Reduce, reuse, waste management	Proposition of a quadrant analysis (avoidance, substitution, disposal, circulation) to be applied in manufacturing factories to mitigate environmental impact.
Marrucci et al. (2020)	Case study	DMAIC, lean six sigma	Carbon footprint, waste management	Tools from lean (e.g. DMAIC) can be useful for supporting the effectiveness of environmental management tools (e.g. carbon footprint) in reducing the environmental impact of waste generation.
Marquina et al. (2021)	Indicator development and case study evaluation	Value stream mapping	Refurbishment, remanufacturing	The application of lean tools, in this case VSM, can indicate different kinds of waste present in circular supply chains; being important to show improvement opportunities.

Paper	Research method	Lean related strategies	Circular Economy related strategies	Main contribution
Minunno et al. (2018)	Literature review	Lean as general concept	Reduce, waste management	The application of lean concepts in the prefabrication industry can be a way of increasing the level of CE adoption in the building industry.
Piyathanavong et al. (2019)	Survey	Lean green	CE in general	Several companies in Thailand are implementing green lean and CE principles.
Polyakov et al. (2021)	Literature review	Lean as a general concept	CE in general	Lean can be considered as one of the pillars that support the implementation of CE. Distributed manufacturing and Flexible customized production are the other pillars.
Sartal et al. (2020)	Case study	5S, standard operation	Reduce	A simple tool from lean manufacturing (e.g. 5S) is capable of achieving water reduction and efficiency without affecting economic performance.
Schmitt et al. (2021)	Case study	Lean as a general concept	Ecodesign, recycle, reduce, remanufacturing, reuse, waste management	The importance of considering a three-level approach in the integration of lean and CE: products, processes, and systems.

5. Discussions

Considering the lean tools reported in the literature, the role played by 5S and VSM can be highlighted. Although the former is one of the most basic lean tools, usually implemented as a first step toward lean thinking in a company, even this basic tool has been found to promote support for the CE. The latter is especially interesting for mapping opportunities to increase value from a lean and CE perspective; it is also a useful way to emphasize the synergies between

the CE and lean. One of the most important aspects of VSM in the CE context is to expand the notion of value considering the end-of-life of products, which is one of the core principles of the CE. Future research could investigate whether the adoption of lean tools in the work/learning environment, resulting in better environmental performance, also leads to better sustainable practices in other sectors, including individual behaviors. This possibility was suggested by Gutierrez et al. (2020), but has not yet been empirically tested.

A lack of studies considering the meso level of the CE is noticeable. At this level, the main CE practices are industrial eco-parks and industrial symbioses, which are fertile fields for conducting studies with a lean perspective. In these environments, the waste of one company is the input for processes in another company. It would be interesting to investigate how lean thinking, which aims to reduce waste to zero, would behave in a context where not all waste is completely undesired. Another interesting point would be to analyze the relationship between lean and CE in the supply chain management context, considering that lean works with small units at a time, which might increase the number of deliveries and, therefore, emissions (Melo et al., 2022).

The main CE practices presented in the articles studied here relate to the R strategies, especially 3R: recycle, reduce, and reuse (Caldera et al., 2019; Ciliberto et al., 2021; Dahmani et al., 2021; Gutierrez et al., 2020; Hedlund et al., 2020; Kurdve and Bellgran, 2021; Lim et al., 2022; Minunno et al., 2018; Polyakov et al., 2021; Sartal et al., 2020; Schmitt et al., 2021). Other R strategies, such as remanufacturing and refurbishment, were also represented, but at a lower scale (Ciliberto et al. 2021; Hedlund et al., 2020; Kurilova-Palisaitiene et al., 2018; Marquina et al., 2021; Schmitt et al., 2021). This is something expected, as the first 3R represent the most basic aspects for considering other waste management practices. Another important practice is ecodesign (Dahmani et al., 2021; Schmitt et al., 2021), which is particularly related to lean, as the design phase has implications for the whole life cycle of a product, including the manufacturing process and the waste that can result from it. Considering the variety of practices that can be linked to the CE, there are several less-studied research opportunities in the lean context, such as cleaner production and production policies (e.g. make-to-order and make-to-stock).

No study has been identified in the literature that proposes a formal definition of the integration between Lean and CE. Thus, this research, in presenting the idea of Circular Lean as the application of lean tools sustaining the achievement of the CE, considers the following main points: (1) the achievement of sustainable development; (2) the transition from a linear

flow to a CE flow, considering waste as an input in a restorative and regenerative environment; and (3) the consideration of the three levels of analysis (e.g. micro, meso, and macro). Including these aspects in the lean principles indicated by Womack et al. (2004), this research proposes that a Circular Lean approach should:

1) Specify value considering every residue as an input, in order to minimize waste and increase value to the whole life cycle;
2) Identify the value flow during the whole life cycle;
3) Make the value flow faster in a circular way, considering the whole life cycle;
4) Pull the value flow considering the integration of the supply chain; and
5) Search for perfection considering the optimization of processes and the mitigation of negative environmental impacts.

The framework presented in Figure 4 summarizes the conceptual development of this Circular Lean concept. The extraction of raw material should be avoided as much as possible in a CE context. In the production phase, lean and CE practices can be adopted to aim for zero waste, relating to both production and environmental indicators. Although the distribution phase is the least studied in the relationship between lean and CE, the necessity of applying green supply chain management approaches to mitigate negative environmental impacts is indicated. The consumption phase should consider environmental value. Thus, companies need to focus CE practices on increasing value for customers while preserving the environment. Companies should also apply green procurement practices in their inputs. Future studies could also provide insights relating to industrial symbiosis in this phase. Finally, waste management practices need to follow the R hierarchy, applying lean practices that increase value in this process and thus supplying the market demand, for example reducing the lead time in remanufacturing processes. Clearly, there is an intersection among all these phases when considering a Circular Lean environment, and that a continuous improvement approach should always be sought. It is important to note how the literature on lean is much more focused on production and waste management phases.

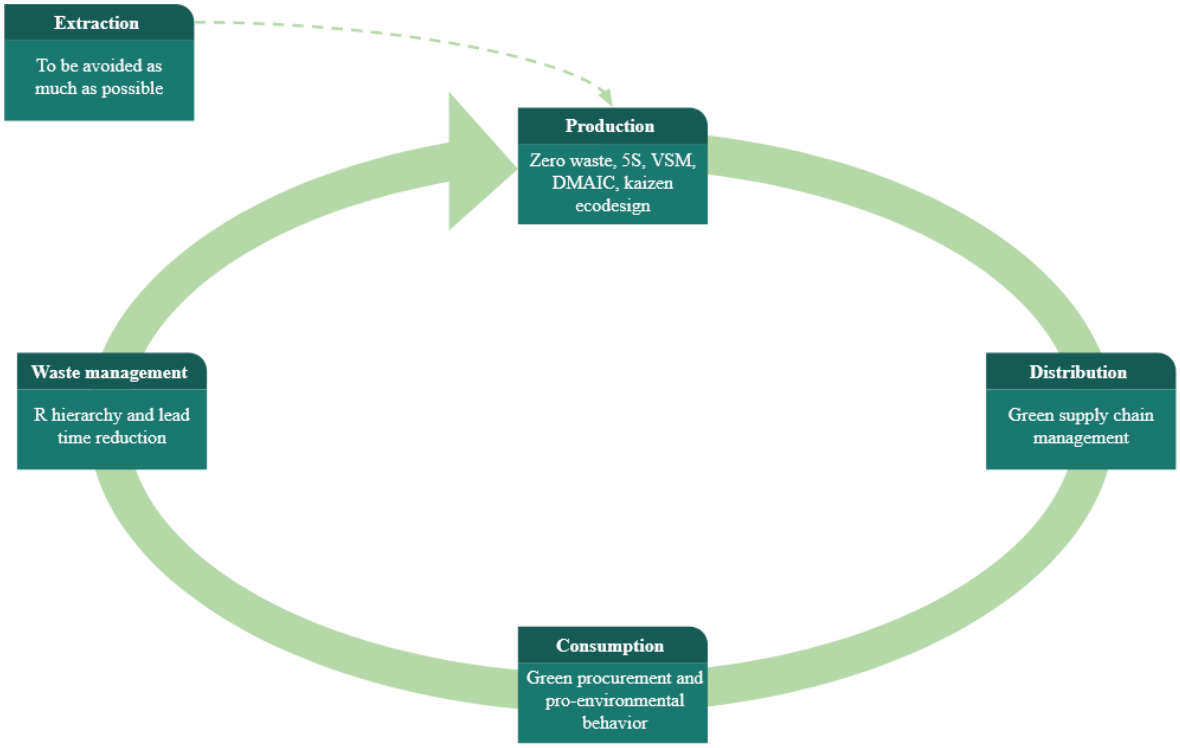

Figure 4 - Circular Lean framework

6. Conclusions

The current production and consumption model - linear - is unviable in the long term, due to the limitation of planetary resources, as well as limited regenerative capacity. Thus, new ways to produce and consume need to be developed if sustainable development is to be achieved. The CE is one of the main strategies that have been developed to accomplish this goal of sustainability. However, companies still face challenges in its implementation. Lean, which enjoys the consensus of an effective approach to optimize processes and minimize waste, has been widely implemented by companies, and might further sustain the increase in circularity in companies.

After reviewing the literature, this research furthers the current perception that lean - as happens in the linear economy - can indeed sustain some aspects of the CE. From a CE perspective, the literature shows that lean can aid remanufacturing processes, minimize waste (e.g. reducing different forms of pollution and the waste of natural resources), increase reuse practices, and expand value perception in products and services. Yet, although these positive outcomes were found in the literature, there is still no formal definition of this relationship. Therefore, this research suggests Circular Lean as the adoption of lean practices that support CE achievement, aimed at sustainable development at the micro, meso and macro levels, in a restorative and regenerative way. This is done by specifying and identifying value, making it

circular during the whole life cycle, pulling this value in an integrated way in the supply chain, and seeking for perfection in terms of the optimization of processes and the mitigation of negative environmental impacts.

The main theoretical implications of this research are the definition proposed for Circular Lean, which could lead future studies in the area to implement analyzes combining these two concepts. The literature mapping is another important contribution, as it shows how the literature has been developing the theme and suggests possible research opportunities to be studied.

The main practical implications of this research are related to the promotion of lean as a supporting approach to achieve the CE. Thus, managers and companies aiming to adopt a more circular organizational environment can rely on the results of this research. For example, the adoption of 5S is a simple but effective starting point for companies, as some studies indicate the positive outcomes of it from both production and environmental perspectives. Companies working in a remanufacturing environment can also take lean into consideration in order to improve performance. Although some supply chains might have barriers to implementing lean practices, they should not be understood as a barrier to applying CE practices. Other operational management approaches could be used in these cases in order to sustain the CE, such as Industry 4.0 tools.

Regarding the limitations of this research, it is important to mention those intrinsically related to the method of literature review. First, some important research studies might not have been found due to the keywords and databases selected. Second, there is the inherent subjectivity in data screening and compilation. Third, the scientific literature tends to publish more positive results, in such a way that negative results are often left unpublished. This research has attempted to mitigate these points by using two of the most renowned databases: Scopus and WoS. In addition, keywords were selected from a pre-analysis of the literature, and an internal peer approach was used for the screening process.

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Declaration of interests

The authors declare that they have no competing interests in this paper.

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