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CIRCULAR ECONOMY AND INDUSTRY 4.0 INTO INDUSTRIAL ENGINEERING COURSES: AN OVERVIEW REGARDING THE INTEGRATION AND FUTURE INSIGHTS[1]

ECONOMIA CIRCULAR E INDÚSTRIA 4.0 NOS CURSOS DE ENGENHARIA DE PRODUÇÃO: UMA VISÃO GERAL SOBRE SUA INTEGRAÇÃO E PERSPECTIVAS FUTURAS

ECONOMÍA CIRCULAR E INDUSTRIA 4.0 EN LOS CURSOS DE INGENIERÍA INDUSTRIAL: UNA VISIÓN GENERAL DE SU INTEGRACIÓN Y PERSPECTIVAS FUTURAS

ABSTRACT

Objective: This article presents a theoretical study of how the concepts of the Circular Economy (CE) and Industry 4.0 (i4.0) can be incorporated and introduced into industrial engineering courses and how they can help the implementation of circular economy business models.

Design/methodology/approach: A theoretical analysis was conducted on a set of articles identified through a search based on the combination of keywords 'circular economy,' 'CE,' 'industrial engineering,' 'industrial engineer,' 'i4.0,' and 'Industry 4.0.' Two databases, Scopus and Web of Science, were consulted initially. A total of 29 articles were selected and utilized for the subsequent analysis. Following a comprehensive review of these 29 articles, we sought to determine how the concepts of the circular economy and i4.0 can be integrated into industrial engineering courses and their potential contributions to the implementation of circular economy business models.

Results: The paper provides an overview of how the concepts of the CE and i4.0 can be incorporated into the curriculum of undergraduate industrial engineering courses, utilizing an interdisciplinary and cross-cutting approach. Furthermore, it was possible to verify that there is a strong and feasible relationship between the concepts of the circular economy and Industry 4.0. For the effective implementation of these concepts, there is a necessity to train professionals and the use of digital technologies in favor of the circular economy.

Originality/value: The paper brings as contribution, the discussion about the importance of incorporating the concept of circular economy and i4.0 into the courses of future engineers, who work mainly in the management of production processes and

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management of resources. This is a theoretical study, not an empirical one, and perhaps this is the main limitation of the research. However, despite being theoretical, it brings as a practical contribution an important discussion about the need to train professionals, even in their undergraduate training, and the use of digital technologies in favor of the circular economy.

Key words: Industrial Engineering. Circular Economy. i4.0.

RESUMO

Objetivo: Este artigo apresenta um estudo teórico sobre como os conceitos de Economia Circular (EC) e Indústria 4.0 (i4.0) podem ser incorporados e introduzidos nos cursos de engenharia de Produção e como podem auxiliar na implementação de modelos de negócios de economia circular.

Design/metodologia/abordagem: Foi conduzida uma análise teórica de um conjunto de artigos identificados por meio de uma busca baseada na combinação das palavras-chave ‘economia circular’, ‘EC’, ‘engenharia industrial’, ‘engenheiro industrial’, ‘i4.0’ e ‘Indústria 4.0’. Inicialmente, foram consultadas duas bases de dados, *Scopus* e *Web of Science*. Um total de 29 artigos foi selecionado e utilizado para a análise. Após uma revisão abrangente desses 29 artigos, buscou-se determinar como os conceitos de EC e i4.0 podem ser incorporados nos cursos de Engenharia de Produção e descrever suas possíveis contribuições para a implementação de modelos de negócios de economia circular.

Resultados: O artigo oferece uma visão de como os conceitos de EC e i4.0 podem ser incorporados no currículo dos cursos de graduação em Engenharia de Produção, de forma interdisciplinar e transversal. Além disso, foi possível verificar que existe uma relação sólida e viável entre os conceitos da economia circular e Indústria 4.0. Para a implementação efetiva desses conceitos, é necessária a capacitação de profissionais e o uso de tecnologias digitais em prol da EC.

Originalidade/valor: O artigo contribui trazendo a discussão sobre a importância de incorporar o conceito de economia circular e i4.0 em disciplinas e nos cursos dos futuros engenheiros, que trabalham principalmente na gestão dos processos de produção e na gestão dos recursos. Trata-se de um estudo teórico, não empírico e talvez essa seja a principal limitação da pesquisa. No entanto, apesar de teórico, traz como contribuição prática uma discussão importante sobre a necessidade de capacitar profissionais, ainda em sua formação de graduação e o uso das tecnologias digitais em favor da economia circular.

Palavras-chave: Engenharia de Produção. Economia Circular. i4.0.

RESUMÉN

Objetivo: Este artículo presenta un estudio teórico sobre cómo los conceptos de la Economía Circular (CE) e Industria 4.0 (i4.0) pueden ser incorporados e introducidos en los cursos de ingeniería industrial y cómo pueden ayudar en la implementación de modelos de negocios de economía circular.

Diseño/metodología/enfoque: Se realizó un análisis teórico sobre un conjunto de artículos identificados a través de una búsqueda basada en la combinación de palabras clave ‘economía circular,’ ‘CE,’ ‘ingeniería industrial,’ ‘ingeniero industrial,’ ‘i4.0,’ e ‘Industria 4.0.’ Se consultaron inicialmente dos bases de datos, Scopus y Web of Science. Un total de 29 artículos fueron seleccionados y utilizados para el análisis subsiguiente. Tras una revisión exhaustiva de estos 29 artículos, se buscó determinar cómo los conceptos de economía circular e i4.0 pueden integrarse en los cursos de ingeniería industrial y sus posibles contribuciones a la implementación de modelos de negocios de economía circular.

Resultados: El artículo ofrece una visión de cómo se pueden incorporar los conceptos de la CE e i4.0 en el plan de estudios de los cursos de ingeniería industrial de pregrado, utilizando un enfoque interdisciplinario y transversal. Además, fue posible verificar que existe una relación sólida y viable entre los conceptos de economía circular e Industria 4.0. Para la implementación efectiva de estos conceptos, es necesario capacitar a los profesionales y utilizar tecnologías digitales en favor de la economía circular.

Originalidad/valor: El artículo contribuye al debate sobre la importancia de incorporar el concepto de economía circular e i4.0 en los cursos de los futuros ingenieros, quienes trabajan principalmente en la gestión de procesos de producción y en la gestión de recursos. Este es un estudio teórico, no empírico, y quizás esta sea la principal limitación de la investigación. Sin embargo, a pesar de ser teórico, contribuye a una importante discusión sobre la necesidad de formar profesionales, incluso en su formación de pregrado, y el uso de las tecnologías digitales a favor de la economía circular.

Palabras clave: Ingeniería Industrial. Economía Circular. i4.0.

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INTRODUTION

The American Institute of Industrial Engineers (AIIE) defines Industrial Engineering as follows: "Industrial Engineering is concerned with the design, improvement and installation of integrated systems of men, materials and equipment. It draws upon specialized knowledge and skills in the mathematical, social, and physical sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems" (AIIE, 2022).

Also, according to AIIE (2022), the prime objectives of industrial engineering are: (1) to increase productivity, (2) to eliminate waste and non-value-added activities, and (3) to come up with the optimum use of scarce resources that would bring out the best results.

It is therefore an engineering that deals with people, material, physical and financial resources, that organize the processes to produce tangible products, but also services, and that uses a series of tools, methods, and a lot of information. Throughout history, industrial engineering has been adapting to various technological and social changes, such as the interchangeability of parts, pull production or the advent of the Internet. In the more traditional view of industrial engineering, we work with flows, in which inputs (such as raw materials and inputs) are transformed into products and/or services. In the various transformation processes, there is a need to apply different concepts or areas of industrial engineering, such as quality management, economic management, product engineering, operational research, programming and production control, among others. After the transformations, industrial engineering is still present in the logistics and transport processes. This strongly linear production model, also known as "take-make-dispose" has been around for many years; but it has been questioned because of the negative and cumulative impacts it causes, especially on the environment (Nitkiewicz & Wojnarowska, 2021).

In other hand, CE has emerged as an alternative that seeks to redefine the notion of growth (Kirchherr et al., 2017). Through three basic principles: i) Preserve and control natural capital by controlling finite stocks and balancing the flows of renewable resources; ii) Optimize resource yields by circulating products, components and materials in use at the highest level of utility at all times, both in the technical and biological cycles, and iii) Stimulating the effectiveness of the system by revealing and excluding negative externalities from the beginning; seeks to dissociate economic activity from the need to consume finite resources, until their inevitable depletion (EMF, 2022). CE has also mobilizing effect on academic curricula topic across industries; new programs, new courses and its topics are being introduced in order to provide knowledge and skills that are appropriate to handle circularity challenge (Nitkiewicz & Wojnarowska, 2021).

Besides that, new technologies, Industry 4.0 or Smart manufacturing also arrive changing the way companies deal with their resources and management. Parida et al. (2019) pointed out that the digital age offers companies many new opportunities to overcome these transformational challenges and jointly advance in sustainability and competitiveness. Bag et al. (2021) reinforces this view, stating that digital technologies provide incentives for companies to implement circular economy principles, enabling new business models, as well as the redesign of products and value chains to suit a new circular economy paradigm.

Another important point is that implementing circular economy projects requires large investments and often leads to longer and more uncertain payback times than traditional projects (Bressanelli et al., 2022b). Besides that, for these concepts to be really implemented, people need to be properly trained to do so.

Trying to solve these problems and difficulties, two complementary bridges emerge: the necessity to train professionals and the use of digital technologies in favour of the circular economy.

Regarding the several digital technologies that can facilitate the transition towards circular economy models in several ways, previous research (Bressanelli et al. 2022b; Beltrami et al., 2021; Cagno et al., 2021) has studied many digital technologies. In this paper we will focus in three of them: IoT, Big Data and Analytics, and Blockchain, given their relevance and potential for the circular economy and relation with industrial engineering courses.

Regardless of the importance of education, especially in the field of higher education, in promoting sustainability, the number of papers addressing the relation of teaching and the circular economy is still limited (Kirchherr, J. & Piscicelli, 2019; Whalen et al., 2018) and also limited studies that properly discuss the need to train engineering students to work with new emerging technologies (Babic et al., 2022).

Therefore, there is a need to train and prepare professionals to deal with these two challenges and new concepts "CE and i4.0", in order to bring a new business model, the circular economy business models. So, this paper aims to present a discussion about how the concepts of the circular economy and i4.0 can be introduced and incorporated into industrial engineering courses in order to facilitate the implementation of new circular economy business models.

The article presents, in addition to this introduction, four more items. The second item briefly reports a history of industrial engineering, in order to contextualize its main characteristics; and also introduces the concepts of circular economy and i4.0. The third item discusses the method used to carry out this study. The fourth item presents the relation between CE and i4.0, focusing in how they can help in the implementation of circular economy business models and also how the international literature has been dealing with the issue of incorporating the circular economy and i4.0 in higher education. Finally, some suggestions and final considerations are presented.

INDUSTRIAL ENGINEERING AND CIRCULAR ECONOMY: CONCEPTS AND HISTORY

Industrial engineering throughout history

The origin and history of industrial engineering alone would make a unique paper. Before the mechanization of production, it is assumed that artisans developed their production processes individually, going from the conception and creation of a product to its finalization, in a little systematized way, and in most cases, seeking to meet a previous demand (Campos, 2021). From the moment that aspects such as systematization, organization, integration, measurement and mechanization had begun incorporated into these processes, industrial engineering is born. At the beginning of industrialization in England (18th century) what we know as production mechanization appears, one of the great milestones of industrial engineering. That is, machines and tools begin to be used, requiring a more adequate treatment to the production processes. But it was in the 19th and early 20th centuries that two paradigmatic figures (Frederick Taylor and Henry Ford) transformed empirical knowledge about production into formally established knowledge. From this point, industrial engineering began with a conception of economic rationality applied to production systems (Campos, 2021). And precisely this concept of "economy mode" was one of the concepts that most changed over time. If before it was the business owners and production managers who defined what was economic and what should or should not be produced, now there is a much broader context with the participation of other types of stakeholders. Environmental liabilities (such as a negative image or costs caused by environmental accidents with worldwide repercussions) or even a more ecological vision of some consumer niches, aroused in organizations a greater concern in relation to their products, processes and impacts that their activities cause to the environment, and today they influence this rationality or economic mode. This, therefore, is one of the major factors that make the vision of the circular economy gain so much attention in recent years, especially in the field of engineering in general.

The concept of circular economy

The topic of Circular Economy (CE) has been one of the most researched and discussed topics in recent years (Sehnem et al., 2019a) and has been pointed out by scholars and policymakers as a promising approach to decouple economic growth from resource consumption and waste generation (Lieder and Rachid, 2016). The origin of the term dates back to the work "Economics of Natural Resources and the Environment" by Pearce and Turner (1990), two British economists, who stated that the traditional open system economy was implemented without an internal tendency towards recycling, observing the predisposition to treat the environment as a large reservoir of waste. This new proposal synthesizes a series of important previous schools of thought, such as Walter Stahel's performance economics, or the Cradle-to-Cradle design philosophy of William McDonough and Michael Braungart, or the idea of Biomimicry articulated by Janine Benyus. The Industrial Ecology of Reid Lifset

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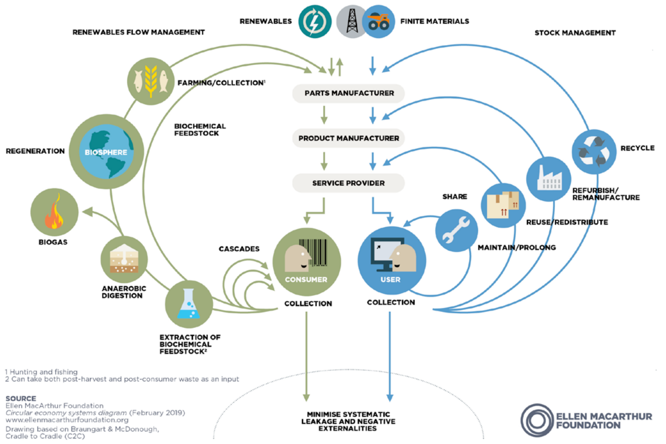
and Thomas Graedel also plays a very important and present role in the EC's vision, as it aims to analyse the industrial system in an integrated way, taking into account its relationship with the ecosystem in which it is inserted. Two other previous initiatives that should be remembered for their contributions are the Natural Capitalism of Amory and Hunter Lovins and Paul Hawkens, and the Blue Economy approach of Gunter Pauli, who previously, in the 1990s, had already spread the ZERI (Zero Emission Research Initiative).

However, the topic gained greater notoriety with the emergence of the Ellen MacArthur Foundation (EMF), in 2010, whose mission is to accelerate the transition towards a circular economy. The EMF (2022) works with businesses, governments and academia to build an economy that is regenerative and restorative from the start. Based on the view that natural resources are finite and that the traditional economic model of "take-make-dispose" is reaching its physical limits, CE emerges as an attractive alternative, which seeks to redefine the notion of growth, with focus on benefits for the whole society. In this line of thinking, the idea is not only to reduce the negative impacts of the linear economy, but through systemic change, to build long-term resilience, generating economic and business opportunities, and providing environmental and social benefits.

The EMF also presents a framework, popularized as the Butterfly Diagram, shown in Figure 1. Besides the three principles of circular economy, the scheme presents ways in which, through two cycles (technical and biological) the circular economy can be implemented in the practice. In addition to this framework, EMF also has another framework developed in partnership with McKinsey&Company, ReSOLVE, which, through 6 sets of actions (Regenerate, Share, Optimize, Loop, Virtualize and Exchange) and the fundamental principles of circularity, shows companies and governments how the concept can be internalized in their actions. The Foundation has also developed and disseminates other practical initiatives that seek to spread the vision of the circular economy, such as: Circulytics, a tool that, through very broad indicators, seeks to measure the circularity of companies. Also, the 'New Plastics Economy', which aims to create momentum towards a plastics system that works. Through the application of circular economy principles, the initiative brings together key actors to rethink and redesign the future of plastics, starting with packaging.

Figure 1.
EMS's Butterfly Framework



Source: EMF (2022).

> "The model makes a distinction between technical and biological cycles. Consumption takes place only in biological cycles, where food and other bio-based materials (such as cotton and wood) are designed to return to the system through processes such as composting and anaerobic digestion. These cycles have regenerated living systems, such as the soil, which in turn provide renewable resources to the economy. Technical cycles recover and restore products, components and materials through strategies such as reuse, repair, remanufacturing or (ultimately) recycling" (EMF, 2022).

In this sense, new business models, the so-called circular business models, will be fundamental. Such models will have the challenge of minimizing the input of materials, as well as the output of unwanted waste in the economic system and play an essential role in the use of resources, aiming at the transition to a more sustainable economic development (Galvão et al., 2020). These models can have different matrices, depending on the sector and the value proposition, involving one or several CE technical cycles, and consequently, generating different MNCs (Guzzo et al., 2020). These models also require greater knowledge about their need for maturity or better conditions for success (Sehnem et al., 2019b).

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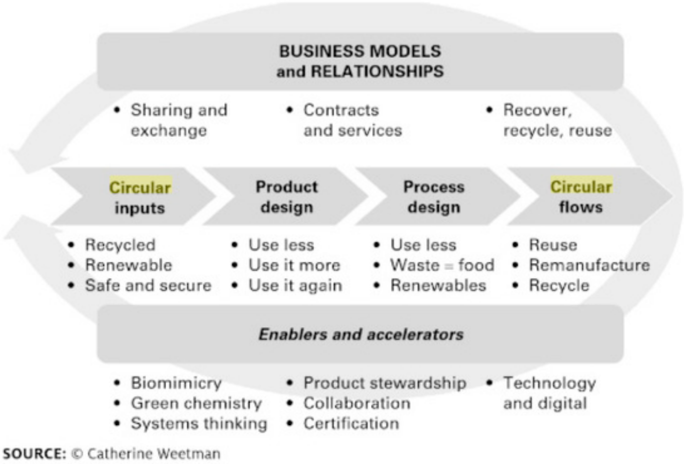
Another well-known framework that drives circular business models is the one presented by Catherine Weetman (Weetman, 2017). In this model (Figure 2) forms of new business models and relationships are presented, such as sharing, exchanging, or the more traditional forms of recycling, recovery and reuse. The framework also presents the process flow, that is, how the circular economy can manifest itself either in the inputs, in the product or process design moments or in the forms of circular flows. And finally, what can actually accelerate the transition to a circular economy, called enablers and accelerators.

Figure 2.
Catherine Weetman's CE Framework



Source: Weetman (2017)

Analysing the history, the concept of the circular economy and the models presented, we observe a series of interfaces that can be explored in order to bring this concept into industrial engineering courses.

The new technologies

In the last few decades the world has changed in terms of technologies in a way never seen before. Telephones became almost a computer. Internet connects us to the world and with one click we have a quantity of information never imaginable before; and, we are always connected (Babic et al., 2022).

In the wave of this new challenge emerge Industry 4.0 technologies (i4.0). I4.0 technologies focus on more advanced factory digitization, and introduction of Industrial Internet of Things (IIoT) with a strive towards modular and efficient manufacturing systems where products could control their own manufacturing process (Lasi et al., 2014). It is also revolutionizing the way companies manage their resources, manufacture, improve and distribute their products. Not only the company itself is affected, but also its network and supply chain. Manufacturers are integrating new technologies, including Internet of Things (IoT), cloud computing and analytics, blockchain and AI and machine learning into their production facilities and throughout their operations.

These new smart factories are equipped with advanced sensors, embedded software and robotics that collect and analyse data and allow for better decision-making (Lasi et al., 2014), and improving and creating value in previous ways of management, such as production operations, ERP, supply chain connections, customer service and other enterprise systems.

This digital technologies lead to increased automation, predictive maintenance, self-optimization of process improvements and, above all, a new level of efficiencies and responsiveness to customers not previously possible.

Developing smart factories provides an incredible opportunity for the manufacturing industry to enter the fourth industrial revolution. Analysing the large amounts of big data collected from sensors on the factory floor ensures real-time visibility of manufacturing assets and can provide tools for performing predictive maintenance in order to minimize equipment downtime (Bressanelli et al., 2022b; Cagno et al., 2021).

Circular Economy and Industry 4.0

With no doubt, Circular Economy and Industry 4.0 are concepts that are arousing the interests of academics and practitioners around the world, whether in the business, social or cultural field, including the university environment. However, it is known that when trying to make this significant transformation towards the circular economy, several technical, operational, organizational, financial and other challenges arise (Bressanelli et al., 2019). We are, for example, talking about challenges related to product and process design, waste management, logistics, remanufacturing, among others. In addition, we also have numerous challenges and barriers associated with low awareness, resistance to change, changing paradigms and mind-sets, among others.

Manavalan and Jayakrishna (2019) assume that the IoT is a technology that describes a network of connected physical objects that are embedded with sensors (such as radio frequency identification (RFID), printed circuits, or electronics). The main idea is to embed products with sensors that will share information and communicate with other systems through the Internet. Thus, they become active participants in the network. In this way, the IoT enables a circular economy by facilitating access to the data of products over their life span (from design and manufacturing to distribution, usage, and end of use) to support their life-cycle management (Ingemarsdotter et al., 2019).

Besides that, the IoT can also enable the provision of product-as-a-service circular business models (such as sharing or pay per use). It allows products to become smart, thus facilitating tracking, monitoring for billing purposes, and the provision of full-service contracts, including repair and maintenance (Bressanelli, 2018). Another contribution is that the IoT can help to track product flows, capture product lifetime information, and minimize the uncertainties involved in recovery strategies, including disassembly (Bressanelli, 2022b).

The second digital technology analysed is Big Data. According to Pagoropoulos et al. (2017), Big Data is characterized by the four V's: Volume, Velocity, Variety and Veracity. As a result, Big Data sets are too large and rapidly changing to be analysed using traditional database techniques or commonly used software tools. Within the context of Circular Economy, Big Data analytics is seen as a viable approach to make use of information from various systems of record such as sensors and IoT, to enable better decision-making. Bressanalli et al. (2022b) also assume that Big Data may provide valuable information on how customer usage patterns can be used to improve product design for circularity. It also can generate an enhanced understanding of user behaviour and provide useful (and often missing) feedback from the product usage phase back to design (Ingemarsdotter et al., 2019).

Finally, the last digital technology with potential to help the implementation of CE is Blockchain. Blockchain is a system of recording information that draws on a digital, distributed ledger of transactions (Bressanelli, 2022b). This ledger is stored, shared, and replicated with multiple participants across a decentralized network in a way that prevents changing, hacking, or cheating the system. Kan et al. (2021) and Kouhizadeh et al. (2020) assume that blockchain can potentially increase firm performance, by adopting circular practices in recycling processes, design, and remanufacturing.

Saberi et al. (2019), Upadhyay et al. (2021) and Böckel (2021) assure in common in their works that Blockchain technology can ensure trust, transparency, traceability, security, and reliability in the value chain, given its distributed digital characteristics. In this way, Blockchain can help products to be tracked in the value chain, including relevant information on their environmental and social conditions at each stage. Thus, Blockchain can be used to ensure that purportedly circular products are environmentally friendly, driving consumer choices and avoiding greenwashing.

METHODOLOGICAL PROCEDURES

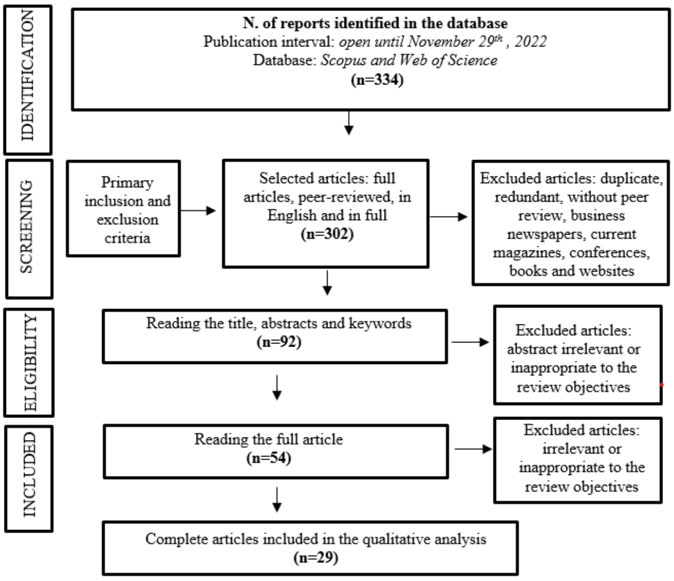
This article is part of more extensive research that seeks to identify possibilities for integrating I4.0 technologies to assist in implementing the circular economy in undergraduate production engineering courses. In this article, to carry out the discussion, bibliographical research was first carried out, which was presented in the sub item "Circular Economy and Industry 4.0" of the item "Industrial Engineering and Circular Economy: concepts and History". Based on this analysis of the texts, a discussion was carried out, presented in the item "Results and discussions".

The theoretical analysis conducted in this article was based on a set of articles whose search was based on the combination of the keywords "circular economy", "CE", "industrial engineering", "industrial engineer", "i4.0" and "Industry 4.0". Two databases were checked and initially (Scopus and Web of Science), after eliminating duplicates, 92 articles were selected from the search for keywords, titles and abstracts. After reading the abstracts, 54 were selected and after reading them in full, 29 were selected and used for the analysis presented.

After reading the 29 articles, we sought to meet the main objective of this paper, which is to identify how the concept of the circular economy and i4.0 can be incorporated into industrial engineering courses and how they can help the implementation of circular economy business models. The Figure 3 shows the process to screening the papers.

DOI: https://doi.org/10.14210/alcance.v30n2(maio/ago).p1-12

Figure 3.
Complete article selection and screening process



RESULTS ANS DISCUSSION

The Circular Economy and Industry 4.0 into Industrial Engineering: insights and proposals

According to Bugallo-Rodríguez and Vega-Marcote (2020) and Babic et al. (2022), Higher Education Institutions (HEIs), through their courses, produce skills and knowledge, and therefore are essential to boost circular economy and i4.0 approaches to reality. They also have the potential to raise the level of sustainable performance (Nunes et al., 2018) and play a valuable (double) role in disseminating CE as a new paradigm of sustainability among their students. First, the university, by teaching the subject to students, can awaken personal actions and values aligned with the vision of the circular economy; and second, it prepares future professionals to incorporate sustainability issues into other educational levels. That is, learning about sustainability and/or circular economy will allow students not only to apply the concepts in their daily lives, but also in their future professional challenges.

The industrial engineering courses in the world have local and regional differences and peculiarities. However, the main areas covered by industrial engineering courses are unanimous in almost all courses around the world. In the case of courses in Brazil, the Brazilian Association of Production Engineering (ABEPRO, 2022) establishes 10 major areas within Industrial Engineering, namely: i) Engineering of operations and production processes (EOPP); ii) Supply chain (SC); iii) Operational research (OR); iv) Quality engineering (QE); v) Product engineering (PE); vi) Organizational engineering (OE); vii) Economic engineering (EE); viii) Labour engineering (LE); ix) Sustainability engineering (SE); and, x) Education in industrial engineering (EIE).

Analysing the Brazilians' Industrial Engineering courses and the ABEPRO's areas, we proposed in this paper six undergraduate courses initially chosen to be explored as bridge for introducing CE and i4.0 into Industrial Engineering courses: i) introduction to industrial engineering (Area: Education in EIE); ii) environmental management (Area: SE); iii) product and design engineering (Area: PE); iv) information management/technologies (Area: EOPP); v) administration and operations of services (Area: OE); vi) logistics and supply chain (Area: SC).

Adapted from Campos (2021), Table 1 presents a summary suggestive of how CE and i4.0 can be addressed within the contents of the undergraduate courses of industrial engineering courses.

Table 1
Summary suggestive of introduce Circular Economy and Industry 4.0 into IE courses

Undergraduate courses (Industrial Engineering)	***EC Content/Thematic Aspect***
Introduction to industrial engineering	Address the main concepts and principles of CE and i4.0, along with a brief history, and CE and i4.0 relationship with other course subjects (such as supply chain, information management, design and product engineering, among others). It is important in this course to emphasize the vision of circularity and use of technology as a principle within the context of Industrial Engineering.
Environmental management	Present general aspects of CE, introduce CE frameworks and models, and the relation between CE and the concepts and practices of environmental management and sustainability, such as LCA, Cleaner Production, EMS, among others. Also important to show examples of how technologies can help environmental management.

DOI: https://doi.org/10.14210/alcance.v30n2(maio/ago).p1-12

Product and design engineering	Relate the concept of CE and circularity to the various aspects of product design engineering, exploring for example concepts such as PSS, modularity, interchangeability, ecodesign, design for environment (DfE), design for disassembly (DfD), among others. Highlighting how new technologies can be used.
Information management/ technologies	Address issues related to data technology, such as IoT, Big Data, blockchain, among others. It is important to explore the i4.0 technologies discussing them in light of EC and together with the various possibilities of support systems that are usually addressed in this type of course.
Administration and operations of services	Discussing issues such as sharing, servitization, service innovation ecosystems, among others, should be explored in the discipline in light of CE and i4.0.
Logistics and supply chain	Properly explore concepts such as blockchain, reverse logistics, green logistics, integrated logistics, international logistics, transportation, logistics network planning, among others, in light of EC principles and i4.0 concept.

Source: Adapted by Campos (2021)

It is important to highlight that the proposal presented above is based on the idea that the concept and practice of the circular economy and i4.0 are introduced in an interdisciplinary and transversal way in the course, in these and all courses that the pedagogical project deems appropriate and aligned with the desired professional skills (Campos, 2021).

In a more specific perspective, González-Domínguez et al. (2020) carried out a research in which they analysed the feasibility of applying circular economy techniques for the design and development of products, through collaborative project-based learning with students from different years of an industrial engineering course in Spain. The answers obtained were statistically analysed and the results indicate that students who had more prior knowledge about the circular economy, valued its relevance more for the design and development of products, as well as for the exercise of the profession. In addition, it was demonstrated that the implementation of circular economy strategies in the design and development of products through collaborative projects allows the acquisition of different knowledge in the themes of ecodesign, product planning and distribution, reuse and recycling. In addition, most students considered that the circular economy should be a complementary discipline and a transversal competence.

Janssens et al. (2021) also highlighted the training line for future professionals to work in the transition to the circular economy. Through a survey carried out with Belgian companies, which already adopt or want to adopt a circular view, the authors used focus group and statistical analysis techniques to identify the main competencies expected of professionals who want to work in these companies. Several types of competences were listed, subdivided into three groups (technical, valorisation and transversal competences). The results showed that soft skills and valorisation skills are as important as technical skills for a circular economy. In the case of technical skills, three stood out: a) knowledge and skills about sustainable energy, b) knowledge about the principles of a circular economy, and c) knowledge to use raw materials efficiently. In the case of valuation competencies: a) being able to create customized business models, b) knowledge about the economic aspects of the environment and ecology, and c) skills in project management and implementation. And finally, in the case of soft skills: a) be Innovative and have an open mind, b) have Critical Thinking, and c) be Visionary. Such results only reinforce the need for further studies on the way to incorporate the concepts of circular economy in industrial engineering courses, as well as reviewing the skills that should be valued in the training of these professionals.

And more specific regarding i4.0 and industrial engineering, Babic et al. (2021) assume that it is essential to align the educational and training resources with the industry's need to hire graduates equipped with in-demand smart manufacturing skills. The authors analysed the current landscape at US-based universities with ABET accredited Industrial Engineering programs to gain insight in the current and future offerings of Smart Manufacturing/Industry 4.0 programs and courses. The study results indicated that more

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than half of the responding universities are or will soon be covering smart manufacturing in their programs. Main topics included in the curricula include Introduction to Smart Manufacturing, Data Driven Analytics (Machine Learning and Artificial Intelligence), Data Analytics Components, as well as Connectivity and Control.

The study highlights the potential that industry 4.0 technologies have to accelerate the transition to the circular economy. Especially to accelerate adoption, systematic use, generation of data for decision-making and productive chaining between stakeholders in a supply chain, including the customer. The possibility of including traceability mechanisms and real-time monitoring of the disposal of obsolete and unused products can serve as a lever for creating marketing campaigns that encourage reverse logistics, new uses, reprocessing of materials for new uses.

Industry 4.0 offers a technological package that provides applied solutions to streamline the productive chain, cooperation, partnership, the generation of databases capable of providing relevant information for decision-making and productive optimization. These are technologies capable of providing significant advances in this transition to the circular economy. They have the potential to generate speed of processes, precision, agility and traceability, so relevant for the active internalization of sustainable operations in organizations.

In this way, an agenda is suggested to promote this productive acceleration of circular business models supported by Industry 4.0. It is recommended:

(i) Engage productive associations, federation of industries, government and regional class councils to promote the transition.

(ii) Expand applied research, which generates solutions to real problems in specific production chains.

(iii) Invest in basic infrastructure, that is, powerful, stable broadband internet with coverage throughout the geographic territory.

(iv) Create regional pilot projects to show that circular ecosystems can generate real-time solutions for different parts of the territory.

(v) Invest in awareness campaigns in favor of active, executable circular systems that generate positive results.

FINAL REMARKS

From the results obtained through this research, especially from the analyzes that culminated in Table 1, it is possible to verify that there is first a strong and possible relationship between the concepts of circular economy and industry 4.0 and that for new circular business models to be implemented in practice, technology is an ally of major importance. A second important point to be raised is that the training and possible adaptation of industrial engineering courses, through the discussion of these concepts in existing courses and/or through the creation of new courses, is also of paramount importance and very necessary. Only in this way, with these new concepts being discussed in the classroom, will we have professionals trained and able to deal with the challenges of this new world, much more digital and sustainable.

The development of skills and competences, already in industrial engineering courses, in line with the concepts of CE and i4.0 are also of great importance for the successful implementation of new circular business models. A closer relationship between practice and theory, bringing the university closer to the market and business reality can also bring significant gains for the incorporation of these new concepts and for a higher quality in the training of these professionals.

Finally, we highlight two more suggestions that we consider important. The training of teachers who work in this area and who perhaps do not have the proper knowledge of these concepts; and, a more integrative and transversal vision, increasingly connecting the concepts of EC and i4.0 in the formation of the industrial engineer.

As limitations of this work, we highlight the fact that it is a first discussion on the subject, qualitative and without practical application. As suggestions for future work, a more structured investigation is proposed, with data collected on how this introduction of the concepts of CE and i4.0 has been taking place in industrial engineering courses.

NOTES

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