Journal of Cleaner Production 393 (2023) 136284

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Industry 4.0 as an enabler in transitioning to circular business models: A systematic literature review

Agnes Toth-Peter [a,*], Rui Torres de Oliveira [a], Shane Mathews [b], Leonie Barner [c], Sandra Figueira [d]

[a] *Queensland University of Technology, Faculty of Business & Law, School of Management, QUT Australian Centre for Entrepreneurship Research (ACE), QUT Centre for a Waste-Free World, Australia*
[b] *Queensland University of Technology, Faculty of Business & Law, School of Advertising, Marketing & Public Relations, QUT Australian Centre for Entrepreneurship Research (ACE), Australia*
[c] *Queensland University of Technology, Faculty of Science, School of Chemistry & Physics, QUT Centre for a Waste-Free World, Australia*
[d] *The University of Queensland, Faculty of Business, Economics and Law, School of Business, Australia*

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Business model
Circular economy
Digitalization
Digital transformation
Industry 4.0
Transition

ABSTRACT

The current planetary crisis and the perceived urgency necessitates more sustainable production and consumption patterns. Businesses, particularly the multinationals, play a key role in transitioning to a circular economy, which provides a promising approach to achieving the UN Sustainable Development Goals. Industry 4.0 technologies can theoretically support this transition and enable circular economy through, for example, data-driven and smart business processes. However, merging these new technologies with a circular economy is not a straightforward and well-established process and it fundamentally changes the business value chain. Therefore, this paper provides a systematic overview to help better understand the transition process to circular business models and the enabling role of industry 4.0. Merging these concepts underlines that many factors are interrelated and should be investigated in a holistic way instead of siloes. The findings imply that changes transcend business boundaries, including new value chain characteristics and operation models and indicate the interconnected nature of certain factors along the product lifecycle, including service-based models, circular design, reverse flows, consumers and users, and collaborations. This paper proposes a conceptual transition framework to address how new circular business models can integrate digitally adaptive transformations and proposals for future research are reflected upon.

1. Introduction

Our world is currently facing numerous environmental, social and economic challenges and the consequences of these challenges can be seen in climate change, pollution, biodiversity loss and resource degradation (Okorie et al., 2018). We have reached a tipping point in what our Earth can sustain and the current living standards are not sustainable in the long-term. The problem can be tied back to the first industrial revolution and the logic our economy is built on. 91% of the world still follows this traditional, linear economic 'take--make-use-dispose' system, which is a driver of our production and consumption patterns (Nobre and Tavares, 2020). While innovations of the industrial revolutions have induced growth, with the growing population and the throwaway consumption patterns, products remain underutilized, are prematurely wasted, and their end-of-life is not generally considered (Rosa et al., 2020).

Therefore, it has become inevitable for production to transition to a more sustainable system and the search for solutions a priority for the social and political agenda globally (Ajwani-Ramchandani et al., 2021b; Bjørnbet et al., 2021). The United Nations Member States have summarized an action plan in the 2030 Agenda for Sustainable Development, articulating 17 transformative Sustainable Development Goals (SDGs) (United Nations, 2015). This initiative shows that there is an interest in finding a balance between human and nature to support the more efficient use of our resources and encourages us to do more and better with less (Tunn et al., 2019). Multinationals are particularly

* Corresponding author.
E-mail addresses: agnes.tothpeter@hdr.qut.edu.au (A. Toth-Peter), rui.torresdeoliveira@qut.edu.au (R. Torres de Oliveira), sw.mathews@qut.edu.au (S. Mathews), leonie.barner@qut.edu.au (L. Barner), s.figueira@business.uq.edu.au (S. Figueira).

https://doi.org/10.1016/j.jclepro.2023.136284
Received 14 November 2022; Received in revised form 27 January 2023; Accepted 30 January 2023
Available online 2 February 2023

well-positioned to tackle this issue due to their overarching footprint (Ajwani-Ramchandani et al., 2021a).

The circular economy (CE) is a new economic model and a promising approach to achieve the global SDGs, which drives transition to a CE (Lahane et al., 2020). The circular logic opposes the traditional linear techniques, which encourages businesses to rethink their strategy, reconsider their waste streams, and reintegrate initially useless materials into their production cycles (Piscitelli et al., 2020). There are additional principles and strategies that promote the CE, including product life-extension strategies and closed resources loops (Bocken et al., 2016; Ellen MacArthur Foundation, 2017).

Technological innovation and digitalization can potentially support the CE transition, and contribute to the product lifecycle management along supply chains (Kumar et al., 2020). Specifically, the recent advances of the fourth industrial revolution, or industry 4.0 (I4.0), such as big data, the Internet of Things (IoT) or blockchain, can establish a connection between virtual and physical worlds and provide access to real-time data (Birkel and Müller, 2021) which contributes to CE business models. For example, Ajwani-Ramchandani and colleagues (2021a; 2021b) show that blockchain can be used to reduce landfill waste, circulate plastic and make multinationals accountable.

Although the CE transition process could theoretically be supported through the adoption of I4.0 (Bag et al., 2021b), the requirements and conditions are not yet fully established and or understood (Kristoffersen et al., 2020). Additionally, the scope of a fully integrated, synergistic frameworks is still not established (Okorie et al., 2018) and it is unclear what types of technologies can support the implementation of CE. Therefore, even with its potential to be a game-changer to world resources consumption and human sustainability (Carraresi and Bröring, 2021), merging the I4.0 framework with the CE is not straightforward. Therefore, it is not surprising that many articles call for a better understanding on the role of I4.0 tools (Antikainen et al., 2018; Pagoropoulos et al., 2017; Tseng et al., 2018). Consequently, this paper investigates: *how can digital technologies and an I4.0 framework enable the implementation of circular business models and CE principles?*

To address this research question, the current paper has adopted a systematic literature review (SLR) approach to examine recent developments in the CE–I4.0 field. Therefore, the aim of this paper is to better understand what type of technologies can be implemented in circular business models and how they support the CE transition process. This SLR has several implications. First, it provides a conceptual systematic overview of the CE transition process and proposes a conceptual CE transition framework, which visually represents the interconnected elements through business model innovation. Second, this model emphasizes the holistic nature of the transition process and warrants investigating beyond business boundaries. Third, this review focuses on I4.0 tools and provides a classification of different integration and adoption opportunities along the transition and business processes. Further, the transition framework and classification of I4.0 technologies can be adopted by businesses as a practical tool to facilitate circular business model changes. This SLR also suggests a future research agenda to advance our understanding of digitally-enabled CE transition processes.

2. Background

2.1. Circular economy

Articulation of the CE concept started in the 1960s (Blomsma and Brennan, 2017). It is a developing concept, with multiple approaches, theoretical and scientific definitions, attributed to seminar thinkers, think tanks, legislative and advisory organizations, academia, and business (Nobre and Tavares, 2020). The CE represents an opportunity to integrate a triple bottom line approach (i.e., three pillars of sustainability: *'people, profit, and planet'*) (Caldera et al., 2019; Geissdoerfer et al., 2017) to reduce consumption and meet the growing needs of the population (Hankammer et al., 2019). Contrary to the open-loop, one-way, cradle-to-grave linear system (Johannsdottir, 2014; Lahane et al., 2020), the CE embodies a closed-loop, cradle-to-cradle system (Caldera et al., 2019), circulating products at their highest utility (Geissdoerfer et al., 2017) for the longest possible period (Hopkinson et al., 2018). The Ellen MacArthur Foundation (EMF) defines the CE as '*an economy that is restorative and regenerative by design*' and summarized its three main principles as *'design out waste and pollution, keep products and materials in use, regenerate natural systems'* (Ellen MacArthur Foundation, 2017, The circular economy section).

The CE proposes a circular logic, which promotes better use of resources through multiple cycles (Ghisellini and Ulgiati, 2020) and product life extension (Bakker et al., 2021), as well as end-of-life (Blomsma et al., 2019) and waste management strategies to replace the end-of-life concept and divert waste from landfill (Bjørnbet et al., 2021). For example, the R-framework or R-concepts represent operationalization strategies and range from the 3R–4R to 10R iterations of circularity (Blomsma et al., 2019). The 3R's, *reduce, reuse* and *recycle* represent basic waste management concepts (Campbell-Johnston et al., 2020), complemented with *recover* in the 4R (Bauwens et al., 2020), *remanufacture* in 5R (Campbell-Johnston et al., 2019) and *redesign* in the 6R (Lahane et al., 2020). The 9R also includes *rethink, repair, refurbish* and *repurpose* (Agrawal et al., 2019) and Potting et al. (2017) added *refuse* as the initial step in 10R, that is, making a product redundant by abandoning its function or offering the same function with a different product (see 10R in Potting et al. (2017)). Further, the EMF developed a tool for product life extension, which contains key business actions, encapsulated by the acronym ReSOLVE: *regenerate, share, optimize, loop, virtualize and exchange* (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015).

Another way to address resource management is by strategies that slow (lengthen or extend the use phase and product value), close and narrow (using less material input) resource loops, which are viewed as new CE business models (Bocken et al., 2016). The CE also promotes servitization (Lieder et al., 2020) and the increasing role of services (Johannsdottir, 2014; Pialot et al., 2017), which affects responsibility and ownership structures (Hankammer et al., 2019). Thus, ownership is substituted by access (de Jesus et al., 2019) and performance, with ownership staying with the provider (Bauwens et al., 2020) and the producer turning into a (service) provider (Frishammar and Parida, 2019). These concepts support resource decoupling, i.e., using less resources per economic activity (Hopkinson et al., 2018) and dematerialization, i.e., reduction of material of any product or service (Agrawal et al., 2019).

2.2. Industry 4.0

Technology is a core driver of change and its integration into business processes was catalysed by I4.0, or the fourth industrial revolution (Wang et al., 2020). I4.0 represents a framework and introduces a new innovative ecosystem and a new wave of technologies. It was introduced by the German Government in 2011 to seek high-tech strategies to increase the competitiveness of their manufacturing industry (Lopes de Sousa Jabbour et al., 2018).

The integration of virtual and physical elements is a main attribute of I4.0, establishing cyber-physical systems (CPSs) and product-service systems (PSS) (Díaz-Chao et al., 2021), which serve to connect machines and devices in a network—or the cyberspace—and physical processes (Lopes de Sousa Jabbour et al., 2018). As a result, the connected machines can communicate and process information (Kumar et al., 2020), which creates smart processes and enables smart working and manufacturing (Kerin and Pham, 2019). The I4.0 technologies can vary according to different interpretations. In general, they embody the Internet of Things (IoT), cloud computing, additive manufacturing (AM) or 3D printing (Lopes de Sousa Jabbour et al., 2018), wireless sensor networks, big data analytics, artificial intelligence (AI) (Díaz-Chao et al., 2021), advanced robotics and autonomous systems, augmented reality (Tozanlı et al., 2020) and virtual reality (Birkel and Müller, 2021), horizontal and vertical system integration, simulation, and cyber security with blockchain (Kumar et al., 2020).

Digitalization is a promising enabler of the CE (Neligan et al., 2022) and the link between CE and I4.0 is viewed as the future of organizations (Yadav et al., 2020), as well as an opportunity to transform the economy's stand on material resources (Heyes et al., 2018) and achieve CE goals (Kumar et al., 2020). de Jesus and Mendonça (2018) note that technology adoption is essential for CE's widespread penetration and the CE-I4.0 link also requires rethinking the business operations along the value chain.

Nonetheless, the CE and I4.0 are both contemporary and novel concepts, and research linking CE with emerging technologies is still in a pre-paradigmatic phase (Pagoropoulos et al., 2017). In current literature, the link between CE and digitalization have generally been investigated by looking at I4.0 as an overarching concept and not always pinpointing specific technology. Therefore, it is necessary to investigate specific technologies in the CE transition and their influence on business models (Rosa et al., 2020). The current paper is aiming to provide a better understanding of how specific I4.0 tools and technologies can be adopted along the business model elements to support the integration of CE principles. In this manuscript, we approach the CE-I4.0 link from a business model perspective.

3. Methodology

This paper has adopted the format of an SLR, which is often used to address specific parts of an important phenomenon that is still not fully understood (Piscitelli et al., 2020). The SLR offers a way to identify issues, patterns and themes, which assists theory conceptualization (Lahane et al., 2020). This SLR brings together the findings of eligible papers in a structured and systematic way to provide a synthesis of studies, following the processes and guidelines established by Salvador et al. (2021b), Tranfield et al. (2003) and Xiao and Watson (2019).

The SLR process follows the three main steps of planning, conducting and reporting the review (Xiao and Watson, 2019). The first step, planning the review, includes identifying the research scope and developing the review protocol (the predetermined plan of the upcoming steps) together with a well-articulated research question (RQ) (Bjørnbet et al., 2021). The second step, conducting the review (Fig. 1), entails the search strategy (including keywords, search terms and databases) and the study selection process (including the eligibility criteria and assessment), followed by the evaluation, data coding, analysis and synthesis process. The last step, reporting, includes writing the report itself and disseminating the findings (Xiao and Watson, 2019).

The search strategy and this SLR followed an electronic, database-driven search (Piscitelli et al., 2020) and selected three databases, ABI/INFORM, EBSCO Host Business Source Elite, and Scopus. The keywords and search terms used in the databases were informed by the RQ (Tranfield et al., 2003) and were evaluated by the research team. The terms included key concepts of *'circular economy'*, *'business models'* and

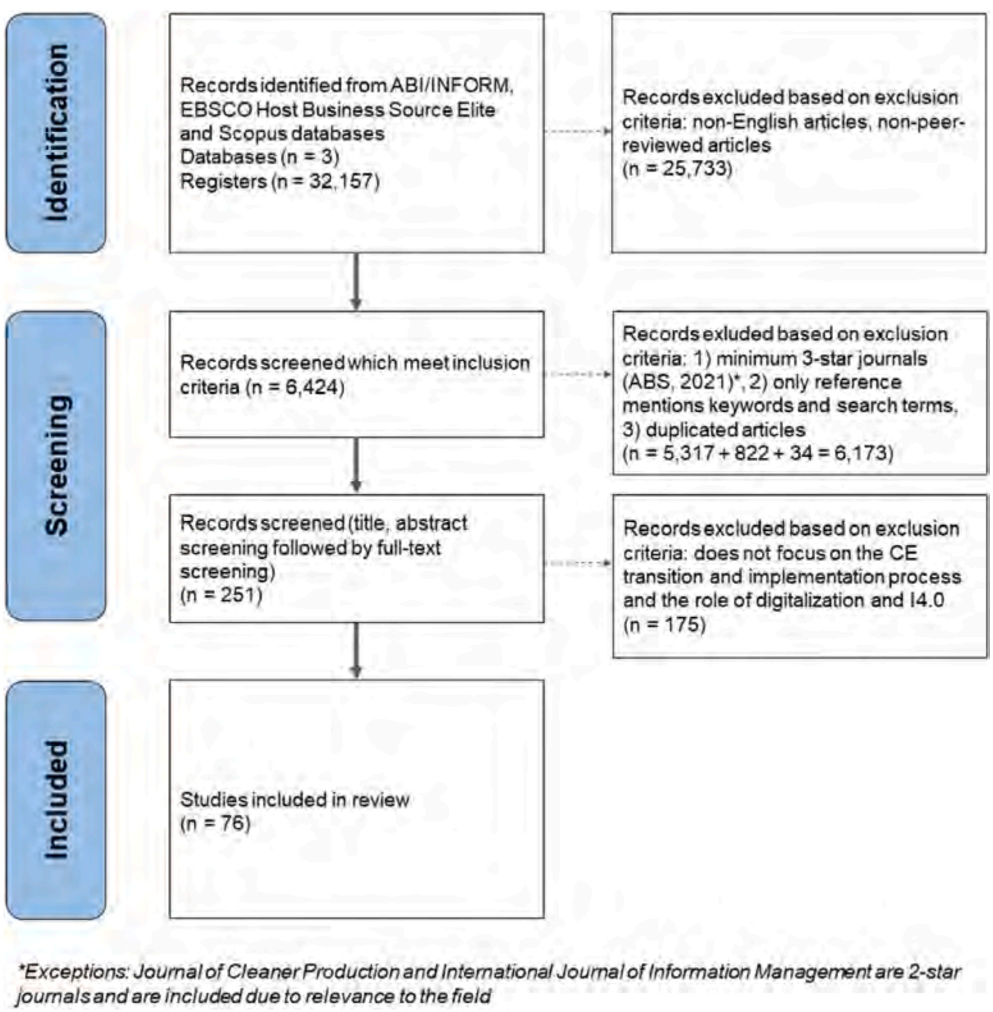

Fig. 1. Overview of literature search and study selection.

'digitalization' and were extended by synonyms and related terms, such as *'closed-loop economy'*, *'strategy'*, *'industry 4.0'* and *'digital transformation'*. The search terms were applied in the full-text (Lopes de Sousa Jabbour et al., 2019; Xiao and Watson, 2019). The search was executed first in March 2021 and then additional searches were done in March and August 2022 to ensure inclusion of relevant studies in the still emerging research area. The integrated search resulted in 32,157 articles.

To select and narrow the list for the review, the study selection process followed the pre-established eligibility criteria (Ahmed et al., 2019). Accordingly, non-English and non-peer-reviewed articles were excluded, but due to the novelty of the concepts, there was no limitation on the time of publication; this yielded 6424 articles. Further, the quality of any review is determined by the literature extracted, therefore, the Academic Journal Guide by the Chartered Association of Business Schools (ABS, 2021) was consulted to seek 3, 4 and 4+ star journals, which allowed the researchers to retrieve high-quality papers, which have appropriate standards and rigorous design (Baldacchino et al., 2015; Harvey et al., 2010). Moreover, the ABS is commonly used tool to scope the literature in SLRs and expand a research field (Christofi et al., 2019; Rojanakit et al., 2022; Wilson et al., 2017). It is important to note that two additional journals were included, despite a ranking of 2 stars only, specifically the *Journal of Cleaner Production (JCP)* and *International Journal of Information Management (IJIM)*. These journals are included to ensure relevance to the topic as prior research showed that these are highly used outlets in the field, and a great number of articles and seminal pieces got published in JCP or IJIM. Exclusion based on the journal quality resulted in 1107 articles. Additionally, to ensure relevance to the topic and contribution to the RQ, articles that only referred to the search terms in the references were also excluded, which resulted in 285 articles. Then, duplicate artices have been excluded, resulting in 251 articles to be analysed.

In the screening process, the titles, abstracts and keywords have been assessed and only articles that focused on the CE transition and implementation process and highlighted the role of digitalization and I4.0 were included. Therefore, articles that investigated the technical, biological and engineering aspects of the CE were excluded (Xiao and Watson, 2019). The screening of articles were conducted by two researchers who worked independently to evaluate the studies and analysed the abstracts and in case of doubt the whole text to see fit between the topic and the papers. The double assessment ensured quality, rigour and minimization of bias (Xiao and Watson, 2019). Finally, 76 articles were identified for the review. No additional searches were conducted to retrieve more documents (Salvador et al., 2021b).

The 76 articles were assessed as a full-text, which included data analysis and synthesis in more detail, and relevant information was extracted and recorded in a comprehensive literature grid table using Excel, for accurate record-keeping of all the articles (Ahmed et al., 2019). The 76 articles were coded using NVivo. The coding process followed a deductive approach and it was based upon previously identified concepts from literature, including CE concepts of design, business models, lifecycle perspective and the main I4.0 technologies, such as IoT, blockchain, big data and additive manufacturing. Additionally, the inductive coding approach enabled the researchers to include new codes, as emerging from the literature, such as an aggregated transition parent code, and included new concepts such as consumers and collaboration.

The papers were clustered and grouped according to these topics and dimensions (Xiao and Watson, 2019). Prior to data analysis and reporting, the emergent themes and the draft of the review were jointly reviewed by the entire research team for consistency, to discuss any ambiguities and to reach a consensus on the overall direction of the review (Birkel and Müller, 2021; Xiao and Watson, 2019). Next, the outcomes are discussed, from a descriptive perspective and a content/theoretical perspective, describing the narrative (Acerbi and Taisch, 2020; Lopes de Sousa Jabbour et al., 2019).

4. Results

4.1. Distribution of articles by year

There were no limitations in time periods when selecting the studies due to the novelty of the topic. The articles covered a period between 2017 to present, showing a steady increase from 2017 and a peak of 27 articles in 2021 (Fig. 2). The CE in combination with I4.0 is a new research area, which justifies this recent peak and the lack of papers prior to 2017. Presumably, the number of publication in 2022 will reach or potentially exceed the number from 2021.

4.2. Distribution of articles across journals

Most of the papers (41 papers or 54%) were published in the *Journal of Cleaner Production*, which is a peer-reviewed, transdisciplinary research platform. This outcome confirms that JCP is a highly used outlet in the field. The two following journals are *Business Strategy & the Environment* and the *California Management Review*, with 10 and 4 publications. The remaining articles were published across 12 different journals, in the fields of business, production and operations management, as well as in hospitality and information management. This highlights the multi-disciplinary interest in the field (Bjørnbet et al., 2021).

4.3. Theoretical approaches

There was no predominant theoretical approach adopted in the studies, and most papers (55 papers or 72%) do not specify a theoretical approach; referred to as *unspecified* (Fig. 3). From those that have a clear theoretical ground, there were 15 different theories adopted, being the most prevalent the stakeholders theory, systems theory, and dynamic capability theory. The lack of an evident theory could be explained by the complex and still emerging nature of the CE-I4.0 link. Given this emerging nature, the CE-I4.0 research is still at its pre-paradigmatic phase (Pagoropoulos et al., 2017) and focus still remains on defining theoretical and paradigmatic clarity, and validity of appropriate tools and language (Blomsma and Brennan, 2017). This explains the difficulty of applying theories. The theories adopted underline the holistic concept of the CE-I4.0 transition, its impact on various stakeholders and implication of resource and capability requirements.

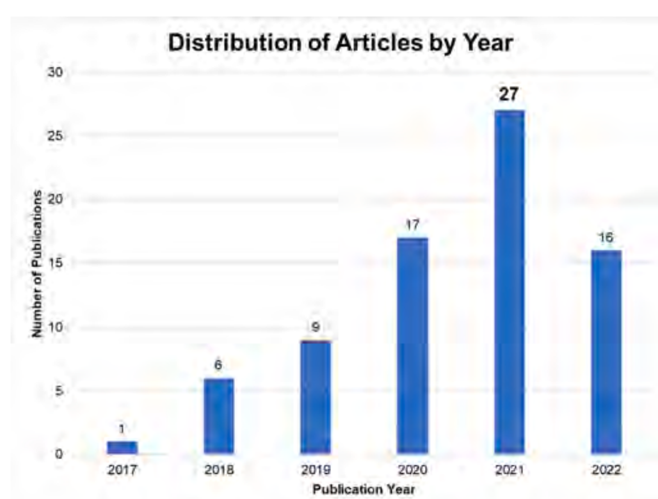

Fig. 2. - Distribution of articles by year (source: Own elaboration) publications for 2022 until August 2022.

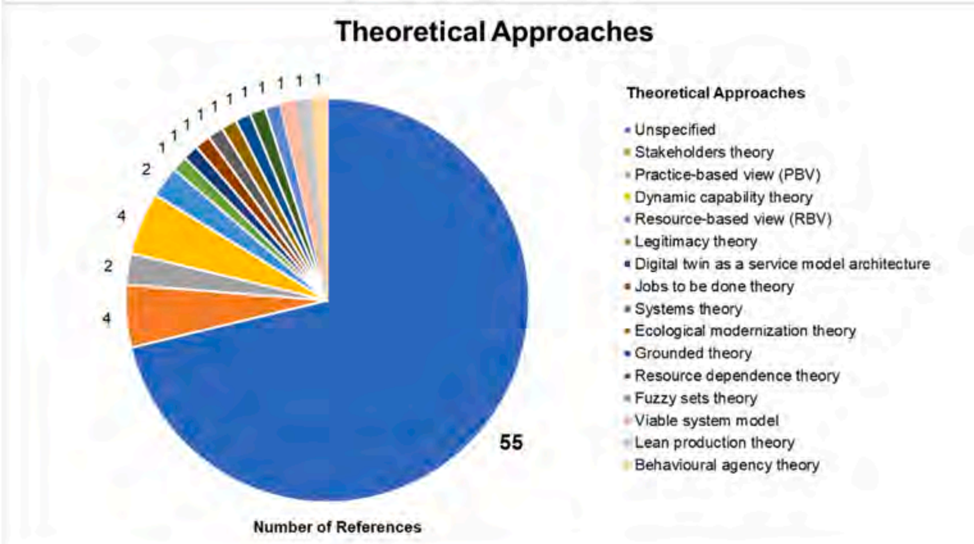

Fig. 3. Theoretical approaches (source: Own elaboration).

4.4. Methodological approaches

Most of the studies are empirical (71%), which aligns well with the urgency of global problems and addresses the lack of practical solutions (de Jesus and Mendonça, 2018). Many of the empirical studies (23/50) are qualitative, and the dominant method is case study approach. Some studies are quantitative (17/50); and the methods include surveys, and in some cases, a type of modelling, such as system dynamics modelling or mathematical modelling. The rest of the studies (10/50) adopted a mixed-method approach, where majorly case studies were paired with a quantitative method such as surveys.

The context and topics of the articles are synthesized in Table I. This manuscript focuses on the digitalization and therefore the role of digitalization and adoption and benefits of I4.0 tools have been evaluated across the themes. According to Salvador et al. (2021a) and Rosa et al. (2020), digital technologies are one of the greatest influences on circular business models, and it is important to include them in a company's value chain and business operations to support the systemic shift to new circular models (Rosa et al., 2020), and sustainable operations management (Lopes de Sousa Jabbour et al., 2018). We aim to address this proposition. Therefore, the table highlights the areas where CE principles were presented or incorporated and specific technologies that contributed to the CE implementation process.

4.5. Circular business models

Our study focuses on business models because businesses are contributing to the currently experienced planetary crisis (Frishammar and Parida, 2019) and, thus, they play a key role in addressing and promoting sustainability (Bag et al., 2021b) and the sustainable development agenda (Franco, 2019), such as *SDG 12 – Ensure sustainable consumption and production patterns* (United Nations, n.d.).

4.5.1. Service-based models

To reduce the environmental impacts and contribute to a more sustainable society, the movement toward services and investigating servitization and service-oriented systems has been growing since the 1990s (Lieder et al., 2020; Stahel, 2010). Service-based models help to reduce the volume of new products, they focus on the service and not the product, and they divert products from landfills. Agrawal et al. (2019) identified four business models in the context of CE implementation; a two-sided, online marketplace model, a servicizing model, a leasing model and a business model that builds upon dematerialization. Service-based models are realized through pay-as-you-go commercial models (Blomsma et al., 2019) and rental or lease agreements (Frishammar and Parida, 2019) and incorporate swapping and sharing of products between consumers through peer-to-peer service platforms which are particularly relevant in the sharing economy (Rojanakit et al., 2022) and are critical to sustainable supply chains (Rajput and Singh, 2019).

Our study identifies digitalization and I4.0 technologies that can support companies' shift to services, functionality and performance-based models (Hopkinson et al., 2018; Lieder et al., 2020). Accordingly, digital sharing platforms help to connect collaborative and temporary users of products and services and facilitate the mobility of unused products (Schwanholz and Leipold, 2020). For example, the study of Rajala et al. (2018) analysed a case in the steel industry, where service-based value-creation was facilitated by a virtual platform and smart contracts. Similarly, Salvador et al. (2021a) noted the role of cloud data and communication technologies in waste exchange platforms. Additionally, Bressanelli et al. (2021) emphasized the role of IoT and big data to facilitate leasing or pay-per-use models.

Servitization is also supported by the newly emerged product–service systems (PSSs), which are promising business models of the CE (Campbell-Johnston et al., 2020). PSS models are based on smart equipment and use big data, operational data and sensing to facilitate linking tangible and intangible elements while satisfying consumer needs (Acerbi and Taisch, 2020; Ajwani-Ramchandani et al., 2021b). The three main types of PSSs are product-oriented, use-oriented and result-oriented models (Rosa et al., 2019; Tunn et al., 2019). Hankammer et al. (2019) analysed the lifecycle of TV and consumer needs and linked the product-oriented model to maintenance, the use-oriented to renting and the result-oriented to watching the TV.

4.5.2. Circular design

In addition to service-based models, the CE requires redesigning products at the beginning-of-life (Hettiarachchi et al., 2022). Accordingly, circular design contributes to minimize waste in production (Khan et al., 2021a), reduce resource throughput over time (Bakker et al., 2021) and enable preventative (Ghisellini and Ulgiati, 2020), predictive (Khan et al., 2018) and maintenance processes (Hankammer et al., 2019). The circular logic requires innovative design elements (Acerbi and Taisch, 2020), such as design for extended use, pre- and post-use, exchange and multiple use cycles (Selvefors et al., 2019), as well as modular design (Hopkinson et al., 2018). Design elements can also be categorized based on slowing (i.e., durability, longevity, upgradability)

Table 1
Themes and role of digitalization with references (source: Own elaboration).

Role of Digitalization	References
SERVICE-BASED MODELS	
•→Big data and cloud data: connect users, facilitates communication through virtual and cloud platforms •→IoT: links tangible and intangible elements, facilitates sharing, leasing and swapping activities and pay-per-use models •→PSSs: creates smart equipment and smart contracts among the users of digital and virtual platforms	Acerbi and Taisch (2020); Ajwani-Ramchandani et al. (2021b); Blomsma et al. (2019); Bressanelli et al. (2021); Campbell-Johnston et al. (2020); Frishammar and Parida (2019); Hankammer et al. (2019); Rajala et al. (2018); Salvador et al. (2021a); Schwanholz and Leipold (2020)
CIRCULAR DESIGN	
•→AI: supports AM techniques, optimization of processes •→AM or 3D printing: during and after use of products, enables adaptability and efficiency, rapid prototyping, connects design and consumers, facilitates the role of material suppliers and customers •→AR: enables collaborations during design phase •→Big data: provides insights into previous product requirements •→PSSs: upgradability enhanced by PSS	Aziz et al. (2021); Bakker et al. (2021); Dahmani et al. (2021); Ertz et al. (2022); Khan et al. (2018); Pialot et al. (2017); Pinheiro et al. (2022); Shayganmehr et al. (2021); Unruh (2018)
PRODUCT LIFE EXTENSION (R-CONCEPTS)	
•→AI: automates processes, enables more efficient use of resources, as a result reduces paper consumption and energy consumption, •→AM: enables more efficient layout of factories, closer production, less transportation, contributes to less waste production •→Big data and cloud data: clearer purchasing specifications, optimization of use materials and usage periods, enable cheaper and cleaner energy •→Blockchain: traceability of products, but requires cybersecurity to ensure provenance of raw materials and to avoid „circularwashing" •→IoT: enables real-time information, data collection and sharing, accuracy and precision, more efficient consumption due to increased control, increased visibility, interconnected relationships, digital traceability, monitoring and tracking •→PSSs: identifies failures and errors, optimizes waste control, enables proactive asset management, preventive maintenance	Agrawal et al. (2022); Ajwani-Ramchandani et al. (2021b); Bai et al. (2022); Dutta et al. (2021); Ertz et al. (2022); Hopkinson et al. (2018); Ingermarsdotter et al. (2021); Kerin and Pham (2019); Lopes de Sousa Jabbour et al. (2019); Pizzi et al. (2021); Rajput and Singh (2019); Wang et al. (2020)
CONSUMERS AND USERS	
•→AM: integrates the role of consumers in design, reduces carbon footprint •→Big data: consumers are both sources and users of data, efficient use of data to monitor usage; "circular-economy data" •→Blockchain: monitors and controls usage (i.e., energy) •→IoT: enables sensor-based, customized, customer-centric solutions and condition-based maintenance	De Giovanni (2022); Hettiarachchi et al. (2022); Khan et al. (2018); Khan et al. (2021a); Kouhizadeh et al. (2020); Luoma et al. (2022); Nag et al. (2021); Zheng et al. (2021)
Role of Digitalization	**References**
REVERSE FLOWS	
•→Big data, cloud data, IoT: enables detailed mapping or movement of product and material flows, asset tracking; optimizes product lifecycle •→Blockchain: contributes to track and trace reverse logistics activities, disassembly-to-order system, real-time monitoring and visibility, traceability and transparency, monitor complex chains, prevent illegal activities and prevent or minimize fraud; incentives for collectors increase the positive impact of blockchain; confidence and trust in return processes due to transparent and secure processes •→I4.0: provides better understanding of the volume, quality, value, and timing of returned products, altering value creation processes and disrupting business models	Ajwani-Ramchandani et al. (2021b); Bag et al. (2021a); Bag et al. (2021b); Birkel & Müller (2021); Ciliberto et al. (2021); De Giovanni (2022); Dutta et al. (2021); Fatimah et al. (2020); Franco (2019); Kerin and Pham (2019); Khan et al. (2021b); Kouhizadeh et al. (2020); Kumar et al. (2020); Luoma et al. (2022); Ma et al. (2020); Mastos et al. (2021); Palmié et al. (2021); Tozanlı et al. (2020); Upadhyay et al. (2021); Yadav et al. (2020)
COLLABORATIONS	
•→Big data: enables hyperconnectivity •→Blockchain: contributes to monitor and control usage; incentivizes tokenizing assets; promotes value circulation and information exchange •→IoT: allows partners to communicate with each other, such as during the recycling process, enables multi-product and multi-machine allocation and hyperconnectivity	Awan et al. (2021); Ciliberto et al. (2021); Di Maria et al. (2022); Hina et al. (2022); Massaro et al. (2021); Mastos et al. (2021); Narayan and Tidström (2020); Palmié et al. (2021); Rajput and Singh (2020); Yu et al. (2022)
TRANSITION AND TRANSFORMATION	
•→Transition goes beyond technological innovation and embraces ecosystem innovation, business model change and changes in value chain •→Transition and integration of technology requires interconnection of different supply chain •→I4.0 positively impacts businesses and drives business model innovation •→Business model change can be established through business model innovation •→Different technology levels are context-dependent (i.e., developing vs developed countries; SMEs; industry) and affect the integration capability •→Assessment and measurement are required to evaluate CE-I4.0 integration dimensions •→There are challenges hindering the CE-I4.0 transition, i.e., digitalization risk related to data safety and security, lack of competence in I4.0 and CE	Bauwens et al. (2020); Belhadi et al. (2022); Chari et al. (2022); Chauhan et al. (2022); Chen et al. (2021); Díaz-Chao et al. (2021); Dwivedi et al. (2021); Gedam et al. (2021); Jones and Wynn (2019); Kayikci et al. (2022); Konietzko et al. (2020a); Kristoffersen et al. (2020); Laskurain-Iturbe et al. (2021); Lu et al. (2020); Mangla et al. (2018); Neligan et al. (2022); Rosa et al. (2019); Tunn et al. (2019); Zheng et al. (2021)

and closing (i.e., disassembly) resource loops (Franco, 2019; Pialot et al., 2017). Nonetheless, incorporating new strategies at the design stage is challenging (Bakker et al., 2021) as it requires thinking and planning ahead (Acerbi and Taisch, 2020), and raises technological limitations, high investments and the need to account for different requirements, capabilities and customer preferences (Pinheiro et al., 2022; Rajput and Singh, 2019).

Our study identifies I4.0 technologies that can facilitate the circular design process. For example, AM/3D printing, through data capture and analysis, can assist the during and after product use (i.e., repair, upgrading, restoration and remanufacturing) by providing additional elements that were unaccounted for (Unruh, 2018). The studies of Dahmani et al. (2021), Aziz et al. (2021) and Ertz et al. (2022) presented the benefits of AM in terms of design flexibility, waste minimization, mass customization and modularization, as well as servitization; given that AM allows rapid prototyping at lower costs, contributes to problem identification at the initial stages and reduces unexpected errors. Accordingly, AM improves product adaptability, process efficiency and accelerates manufacturing processes (Bakker et al., 2021; Shayganmehr et al., 2021). However, one trade-off is the potentially increased energy consumption of one-piece production (Birkel and Müller, 2021), high levels of toxicity (Bauwens et al., 2020), and that personalization and mass customization cannot be aligned with standardization (Selvefors et al., 2019).

Further, Aziz et al. (2021) comment on the role of AI in optimizing AM applications in design, and Dahmani et al. (2021) on the role of big data to provide insights into previous product requirements and augmented reality to enable collaborations during the design and creation phases. Similarly, Pinheiro et al. (2022) tested the role of I4.0 technologies and also found AI and big data to be the most relevant design enablers. Design can also be supported by PSSs, and Khan et al. (2018) and Pialot et al. (2017) conceptualized an upgradable PSS model, as a new mode of design (Pialot et al., 2017) and a new mode of consumption (Khan et al., 2018). They underlined the role of data-driven intelligence in use- and result-oriented models and its contribution to a functionality economy.

4.5.3. Produce lifecycle management

Circular design inherently brings attention to the lifecycle management of products and supports life extension strategies (i.e., 10R concepts (Potting et al., 2017) or ReSOLVE (EMF)) which are at the core of the CE. A lifecycle focus introduces additional concepts, such as extended producer responsibility (Campbell-Johnston et al., 2020) and pre-market producer responsibility (i.e., taking responsibility *before* bringing products to the market) and prioritizing waste avoidance to management (Maitre-Ekern, 2021). Responsibility—and lack thereof—was a core argument of Ajwani-Ramchandani et al. (2021b).

In this manuscript, we show examples of the ReSOLVE framework to facilitate product lifecycle management. For example, Lopes de Sousa Jabbour et al. (2019) focused on capacity building and operations management decision-making and used the ReSOLVE framework to support product design, logistics, supply chains, and production planning and control. Similarly, Pizzi et al. (2021) connected ReSOLVE to financial services and financial technology (FinTech) and analysed their role in enabling a CE and easing financial difficulties.

Our study identifies I4.0 technologies that support lifecycle management, specifically their contribution to end-of-life management. For example, Kerin and Pham (2019) discuss the role of IoT and interconnected relationships in remanufacturing for maintenance, assembly and disassembly and the replacement of faulty product elements. Similarly, Bai et al. (2022) and Bag et al. (2021a) connected I4.0 technologies to the 3R and 10R concepts. Their studies highlight the enabling role of automated disassembly, modular design technology and digital traceability (i.e., of minerals) as well as the positive moderating effect of I4.0 on advanced manufacturing capabilities. Smart disassembly was noted as an emerging trend in logistics and manufacturing supply chains (Agrawal et al., 2022).

Further, Ertz et al. (2022) and Rajput and Singh (2019) also highlighted the role of IoT and AI in product lifetime extensions (i.e., remanufacturing and recycling), specifically supporting the use phase of a product. Accordingly, IoT allows monitoring and tracking, and AI automates the processes provided by big data. This enables smart resource management and supports proactive asset management and preventive analysis during the use phase (Hopkinson et al., 2018). Therefore, companies are able to use products, space and storage more efficiently (Ajwani-Ramchandani et al., 2021b; Dutta et al., 2021) and to accurately and reliably diagnose faulty products and to adapt to harsh environmental conditions (Wang et al., 2020). For example, Ingemarsdotter et al. (2021) investigated IoT in condition-based maintenance and identified challenges and recommendations to support its implementation. Similarly, Wang et al. (2020) developed and tested a novel PSS model in a Chinese manufacturing firm to support active preventive maintenance. Their model enabled real-time status, lifecycle focus, a multiplayer lease and share-based system in a decentralized manner which fundamentally changed ownership models (from independently to centrally owned and accessed by users).

4.5.4. Reverse flows

Reverse flows are key enablers of CE (Ciliberto et al., 2021; Vinante et al., 2021) and the core of circular business models (Hopkinson et al., 2018). A reverse supply chain consists of one flow forward from business to consumers and another reversed flow, where the product is returned (Agrawal et al., 2019) and re-enters the forward chain and a secondary market (Johannsdottir, 2014; Lieder and Rashid, 2016). Accordingly, reverse flows contribute to product recovery and product life extension (Tozanlı et al., 2020). Reverse flows can be established in internal loops (within manufacturing firms), post-business models (distinct business entities), post-consumer models (integrating customers and businesses) and post-society models (involving recycling) (Johannsdottir, 2014). Therefore, their reach go beyond single businesses. Bakker et al. (2021) note the three roles of *facilitators*, *redistributors* and *doers*, who undertake remedial actions to close the gap between suppliers and customers and avoid obsolete products. Once the products are returned, the lost value can be restored by integrating R-concepts (Lopes de Sousa Jabbour et al., 2019), and waste can be used as a resource instead.

Nonetheless, managing the reverse flow activities present challenges and uncertainties due to lack of visibility and supply chain responsiveness as well as bottlenecks. Consequently, businesses face difficulties to plan the volume, timing, quality and value of incoming products (Bag et al., 2021b; Hopkinson et al., 2018). In addition, end-of-life activities of reverse flows are closely tied to and influenced by the beginning-of-life activities. Design, for example, plays a significant role in managing and sustaining the product at its end-of-life (Hopkinson et al., 2018) and in integrating the R-concepts (Agrawal et al., 2022). Accordingly, return processes can be hindered by complex packaging and recycling, and materials that contain unknown or toxic chemicals (i.e., plastic waste and its hazardous substances (Campbell-Johnston et al., 2020; Veleva and Bodkin, 2018).

Further, there is an interesting paradox regarding the prominent dynamic relationship of design and returned products. Notably, Birkel and Müller (2021) and Franco (2019) show that longevity, long-life design and extending product lifetime could result in fewer products returned and recycled, which might negatively affect the continuity of CE, the job of recyclers and manufacturers and increases the uncertainty of resource planning. Therefore, the success of CE is dependent on transparency across the value and supply chain (Ajwani-Ramchandani et al., 2021b) to ensure the visibility and traceability of data (Bjørnbet et al., 2021) and products (Nag et al., 2021).

Our study identfies I4.0 tools and digital interconnections that support the management of return processes and address the occurrent uncertainties. In general, I4.0 tools can improve the understanding of the volume, quality, value and timing of returned products (Birkel and Müller, 2021). For example, front end technologies (i.e., smart manufacturing, smart supply chain and smart products) as well as base technologies (i.e., IoT, cloud and big data) allow companies to monitor demand and the detailed mapping or movement of product and material flows (Ajwani-Ramchandani et al., 2021b) including resource sharing (Palmié et al., 2021). By enabling monitoring, end-to-end visibility and automated functions, I4.0 tools allow companies to capture, analyse and report data to assist with asset tracking (Yadav et al., 2020), which allow having access to their availability, location, condition and real-time visibility (Bag et al., 2021b; Dutta et al., 2021). Accordingly, companies can oversee the whole product life from design to delivery (Kumar et al., 2020), which help to mitigate the ambiguity and mismatches of supply and demand (Ma et al., 2020) and optimize the product lifecycle through the value chain and reverse supply chain (Kerin and Pham, 2019). For example, Fatimah et al. (2020) present a case where an automated smart system was implemented to collect and analyse waste-related information, which is monitored on a dashboard and shared across the organization.

Many studies specifically looked at the role of blockchain technology to facilitate different aspects of reverse activities. Tozanlı et al. (2020) investigated the return and disassembly process of game consoles and implemented an intelligent-, IoT- and blockchain-based disassembly-to-order-system in their six-station disassembly line (to account for the six components of the game console). Similarly, Mastos et al. (2021) used a blockchain application to track and trace the wood (i.e., wood wastes and energy) and reported of both environmental and financial savings as a results. In addition to traceability and transparency, Upadhyay et al. (2021) referred to the benefits of blockchain in CE in terms of facilitating smart contracts, enabling decentralisation, reducing transaction costs and carbon footpring and minimising and preventing fraudulent activities. In another case, De Giovanni (2022) found that offering collector incentives increases the impact of blockchains on closed-loop supply chains and reverse activities due to the smart contracts that align firms and contractors because it ensures that collectors only get incentives upon successful collection. Further, the study of Kouhizadeh et al. (2020) included additional examples of Walmart to track and control their food product supply chain networks, Toyota to manage returned and recalled vehicles, and UPS to measure the optimal route for packages; among others. These digitally-enabled systems supported real-time monitoring and improved the transparency of closed-loop supply chains. The ability of real-time monitoring was demonstrated by Khan et al. (2021b) too, and reportedly contributed to reducing carbon footprints. Similarly, the role of transparency was noted by Luoma et al. (2022) who deemed transparency and traceability more important than the use of data itself.

4.5.5. Consumers and users

Consumer acceptance is key to the success of the CE, and it is important to align the value propositions to the target customer segments (Nag et al., 2021; Salvador et al., 2021a) and to account for their changing needs (Bressanelli et al., 2021). For instance, Lieder et al. (2020) investigated washing machines and leasing and sharing attributes and concluded that renting-out upgradable machines for monthly fees was the most promising model according to consumers. Similarly, Hoffmann et al. (2020) investigated cloth diapers and found cloth diaper-as-service models to be the most environmentally friendly. Further, Agrawal et al. (2022) noted circular supply chains as a necessary infrastructure to enable consumers to return their products and to create value.

Our study identifies I4.0 technologies that are targeted at consumers and users. Integration of IoT, big data and cloud can track user behaviour and enable advanced and customized services for consumers (Zheng et al., 2021). For example, in the context of sustainable smart factories, Khan et al. (2021a) discussed the role of IoT and sensor-based architecture in creating customized customer-centric solutions allowing consumers to monitor their energy usage. This process also builds upon big data analytics to link data to each user. The study analysis of Kouhizadeh et al. (2020) exemplified similar cases, such as customers of Bosch who can use a blockchain-powered refrigerator, in a safe and transparent way to monitor and control their energy usage.

In another study, Hettiarachchi et al. (2022) investigated the role of AM to CE implementation, and they highlighted the role of consumers, both in terms of having an impact on the design phase as well as influencing the location of manufacturing, which can contribute to reducing carbon footprint. Further, Luoma et al. (2022) emphasized the collaborative effort in the CE and underlined the role of consumers in supporting the sustainable consumption of textiles. As such, consumers both use and provide data, hence their acceptance of circular solutions contribute to the feasibility of data-driven solutions. The authors referred to this as *'circular-economy data'* which refers to multiple data sources and through the product lifecycle. Therefore, imbedded intelligence with the help of big data in the textile industry can improve the understanding of the product lifecycle, related responsibilities and uncertainties. On the one hand, De Giovanni (2022) highlighted that transparent and secure processes–enabled by blockchain–can improve consumers' acceptance rate of refurbished products. On the other hand, recording all kind of information about consumer usage can be hindered by privacy protection wishes and cultural barriers.

4.5.6. Collaboration

Envisioning a CE means transitioning from a linear, firm-centric to a circular, network-centric system (Carraresi and Bröring, 2021). The CE accounts for the entire product lifecycle and business processes (Blomsma et al., 2019), product and material flows before, during and after their end-of-life, integrating both supply and demand sides (Franco, 2019), including circular design and reverse flow activities. Therefore, the integration of CE strategies transcends business boundaries, which requires the mobilization and integration of other parties and strong coordination and interconnections among supply chain actors to achieve optimum communication, monitoring and information sharing (Kayikci et al., 2022; Mangla et al., 2018).

Our study shows that I4.0 tools can contribute to and facilitate collaborations across supply and value chains (Awan et al., 2021; Yu et al., 2022). For example, Palmié et al. (2021) underlined the role of orchestration in resource-sharing strategies in their case of Virtual Power Plants in the energy sector. Rajput and Singh (2020) proposed a mathematical model to establish an I4.0 facility that builds upon multi-product and multi-machine allocation to capture real-time data. With this model they aim to overcome the challenges of cleaner production (a precedent of CE). Specifically, Narayan and Tidström (2020) investigated blockchain technology in cooperation and coopetition to incentivize tokenizing assets and promote value circulation. They commented on the complex set of alignments across companies. Similarly, Mastos et al. (2021) studied a digital supply chain management ecosystem and highlighted the role of blockchain to faciliate collaborative procedures and information exchange. They reported energy, emissions and cost savings as a result. Additionally, Awan et al. (2021) also commented on the role of IoT and big data to achieve hyperconnectivity among stakeholders and Massaro et al. (2021) looked at IoT sensors to facilitate communication among different supply chain partners, but the authors warrant further analysis on the co-creation and co-prodution side to understand the dynamics of these syngergies. For instance, they highlight the role of participatory processes, such as participatory design.

Nonetheless, the CE implementation remains challenging due to the different stakeholder interest, expectations and influence (Awan et al., 2021; Ciliberto et al., 2021). For example, in the case of Pinheiro et al. (2022), the suppliers played a more powerful role in fostering CE initiatives, as opposed to the government. Additionally, there are trade-offs and barriers related to I4.0 technologies (Hina et al., 2022). For example, the high level of interconnectivity introduces a fear of security risks (Bag et al., 2021b; Birkel and Müller, 2021). In the case of De Giovanni (2022) and Wang et al. (2020), sharing customers' sensitive information in a centrally owned system was a main risk. Laskurain-Iturbe et al. (2021) and Shayganmehr et al. (2021) also stressed the critical role of data safety and security, in terms of information and the provenance of raw materials as well as considering staff privacy, critical data and data leakage.

4.6. Transition and transformation

Implementing a circular business model and digital tools modifies a business's entire value chain (Rosa et al., 2019), which would evidently necessitate an organisational change process. One mechanism to establish and transition to a new business model is through business model innovation (Tunn et al., 2019), which encompasses changes in value proposition, value creation and delivery, and value capture (Konietzko et al., 2020a; Whalen, 2019).

Additionally, it is evident that I4.0-enabled smart processes introduce a constantly changing phase of digital transformation (Bag et al., 2021b; Díaz-Chao et al., 2021) which drives business model innovation (Chauhan et al., 2022). Dahmani et al. (2021) and Chari et al. (2022) commented on the role of management systems, data analytics capabilities and leadership and strategy capabilities to support the CE-I4.0 transformation. Aziz et al. (2021) and Shayganmehr et al. (2021) emphasized the need of an appropriate infrastructure to store and analyse the huge amount of data and Kristoffersen et al. (2020) developed a comprehensive framework, the *Smart CE*, which identified technical, operational and business analytics capabilities across data-transformation levels, and resource optimization capabilities and data flow, which all build upon a high level of digital maturity. Therefore, we underline why there is a need to create a new business model and we represent digitalization as a diriving force behind new business models (Neligan et al., 2022). However, the level of technology required for a CE remains a critical barrier in the developing-economy context (Gedam et al., 2021).

Additionally, transitioning to a new system calls for better assessment and measurement tools to evaluate the integration of the CE–I4.0 concepts. For example, Belhadi et al. (2022) developed a CE-I4.0 integration index, which builds upon 8 categories, Chen et al. (2021) conducted a regional performance analysis in China, analysing closed-loop network data and cooperation between subsystems, and Kayikci et al. (2022) looked at the maturity and readiness of SMEs to implement CE-I4.0.

5. Discussion

Based on the findings, we propose a conceptual transition framework (Fig. 4) to represent the shift from a traditional business model to a circular business model. We explain how we articulate this framework and how we position CE principles and integrate I4.0 tools to achieve the desired end state. We approach this transition through the mechanism of business model innovation and highlight connections among different elements of circular business models. We aim to demonstrate why transitioning to a CE requires a new mindset (Birkel and Müller, 2021)—i.e., a systems thinking approach (Campbell-Johnston et al., 2019) and a whole-system mindset (Brown et al., 2021)—to go beyond isolated measures (Inigo and Blok, 2019).

Our framework is a simplified representation of the CE transition process. Its aim is to show the connections among the following elements and highlight the enabling I4.0 technologies. The framework intends to underline directions where a business needs to or can be expected to make a change or innovate during the CE implementation.

Our framework includes service-based models because they support CE principles by focusing on the service and functionality aspect rather than the physical products and thus contributes to reducing waste at landfill. Service-based models inherently impact consumer activities and include sharing activities via online marketplaces, leasing and renting activities. Service-based models are enabled by virtual platforms, cloud data, big data, IoT and PSSs.

Our framework highlights the important role of circular design because design defines product characteristics early on and has a direct impact on produce lifecycle extension and end-of-life management. We found that AM/3D printing is a key enabler of circular design and supports efficiency, increases flexibility and reduces waste and cost. It can also be supported by big data, AI and AR. PSSs also play a key role, both as a design and a consumption concept. We note the potential trade-off of increased energy consumption and the tension between personalization and standardization.

We include product lifecycle management in our framework because it impacts the entirety of circular business models and it emphasizes the CE's lifecycle focus, that is, the beginning, middle and end-of-life of products. The ReSOLVE framework is highlighted as a support tool and we underline IoT, AI, big data and PSS as potential enablers, and the role they play to enable repairability, assessmbly and disassembly, monitoring and tracking, as well as proactive asset management.

While design impacts the beginning of life, CE also puts an emphasis on the end-of-life management. Therefore, we highlighted reverse flows

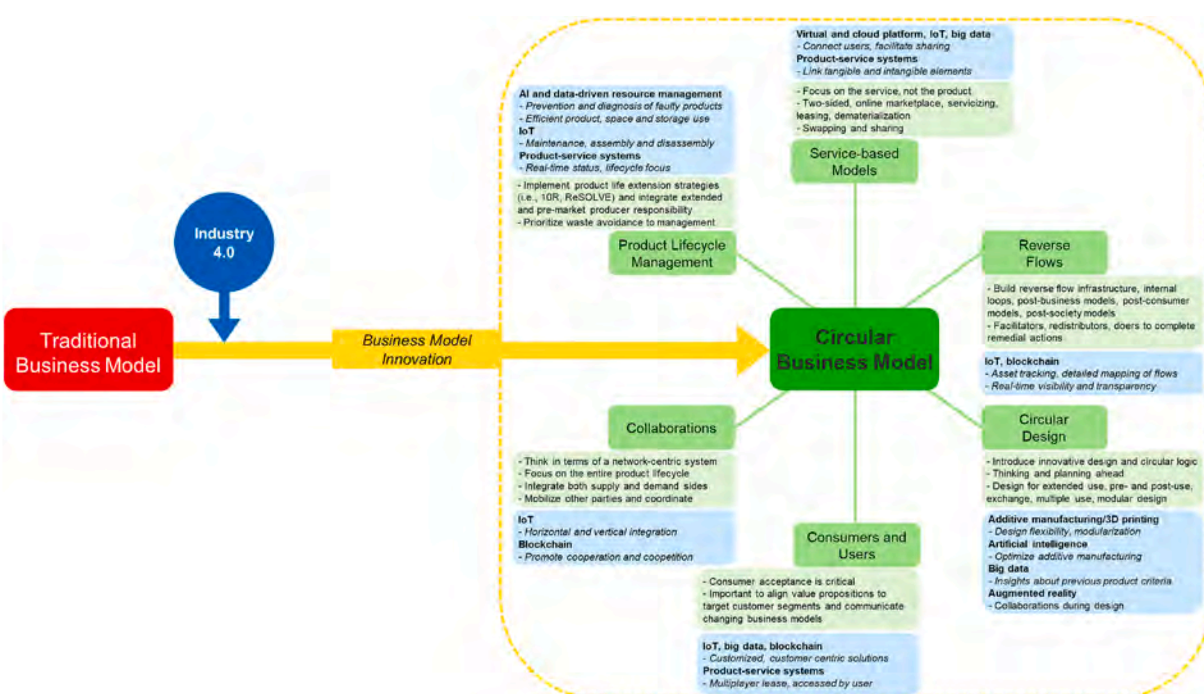

Fig. 4. Conceptual transition framework from traditional linear to circular business models (source: Own elaboration).

in our framework because these reverse mechanisms support the end-of-life perspective (to close the loop), including the return, retrieval and circularity of products (Dutta et al., 2021). We found that reverse flow activities can be supported by IoT and blockchain to increase transparency, traceability and big data and cloud data to provide real-time visibility and tracking. Circular design can influence and support the recovery options and end-of-life management and return options imply changes in the value propositions of consumers and the way they interact with products. We note the trade-off highlighted in the dynamics relationship between design and reverse management.

From the operations side, it is up to the businesses to implement service-based models, introduce new design and build a reverse infrastructure to support the CE. Nonetheless, these changes will directly impact how the consumer uses a product or service and how businesses create value for their consumers (Dahmani et al., 2021). Therefore, our framework highlights the role of consumers to acknowledge their interconnected relationship to reverse flows and design and thus emphasising their role in circular business models. We found IoT, big data, blockchain and cloud technologies as enablers of user behaviour in terms of tracking and providing customised services.

As a final element, we highlight the role of collaborations in our framework, which implies down and upstreams in the supply chain and the transcending nature of CE. We highlight the role of IoT and blockchain to facilitate the integration of different stakeholders along the supply and value chains. We note the trade-off related to increased connectivity and the issues related to security and data leakage.

Therefore, our proposed framework speaks to the interlinked changes across systems, processes, communication, relationships (Birkel and Müller, 2021) and value creation (Ajwani-Ramchandani et al., 2021b). This framework is approached through the lens of business model innovation, but the transition to a CE embraces multiple aspects of innovation, i.e., hard–soft dichotomy of innovation to CE (de Jesus and Mendonça, 2018), including cultural aspects and non-technological elements (Heyes et al., 2018). Therefore, context, industry, technology levels and the configuration of governance matters (Bauwens et al., 2020; Chauhan et al., 2022) and the framework might need to be adopted accordingly. Although there are still operational barriers, challenges and limitations to be considered (Dwivedi et al., 2021; Mangla et al., 2018; Rajput and Singh, 2019; Tura et al., 2019), merging CE and I4.0 holds opportunities for businesses (Díaz-Chao et al., 2021; Lu et al., 2020) and we aim to contribute to the transition trajectory by highlighting certain elements of circular business models and the role of I4.0 tools within. It is important to note that the elements in this framework might not be exhaustive to the circular business model concept, and thus can be expanded.

6. Implications

6.1. Theoretical implications

This study provides a theoretical advancement in the context of business model innovation to a digitally enabled circular system, which we discuss next. First, this review has put forward a conceptual transition framework (Fig. 4) and reported on its points. The interconnected representation across these parts implies that the CE transformation is not an independent process, and it warrants businesses to analyse and understand the complex relationships among different elements (Frishammar and Parida, 2019). Whereas past research has looked at the operational side and activities of business model change, such as the four-phase framework of Frishammar and Parida (2019), in this manuscript, we visualized a transition model, which emphasizes the role of *service-based models, reverse flows* and *circular design* in circular business models, and their connection with and influence on the previously mentioned factors that should be considered in a business model innovation. Our proposed model goes beyond the business activities of the ReSOLVE framework and approaches the transition process through high-level, interlinked system elements. Thus, we extend the themes highlighted by Bjørnbet et al. (2021) and the framework of Hina et al. (2022) and clarify why the CE transition process cannot be implemented through a siloed perspective.

Second, this review focused on the supporting role of I4.0 technologies, which were represented as enablers in the conceptual transition framework. This review provides a classification of different integration and adoption strategies and examples (Table I). Accordingly, this review extends current literature and pinpoints I4.0 tools throughout the transition model. For instance, it highlights the role of AM in design (Unruh, 2018), the role of blockchain in collaborations (Narayan and Tidström, 2020), and the role of IoT in the management of returned products (Tozanlı et al., 2020). Thus, we extend the activities covered by Laskurain-Iturbe et al. (2021) (i.e., R-concepts) and we pinpoint additional areas where I4.0 are presented as enablers, such as collaborations and design.

Finally, this paper advances a conceptual model to demonstrate the systemic nature of the CE transition, which goes beyond business model innovation and embraces the role of ecosystem innovation (Konietzko et al., 2020b). The conceptual model points out how one business's strategy could transcend and impact other supply and value chain members and actors in its closed loop, i.e., customers, who are often neglected in CE transition discussions (Inigo and Blok, 2019). This review confirms and extends the previous research of Agrawal et al. (2019) and pinpoints *how* and *why* circular design, reverse flows and consumers interconnect. This review aligns well with the integrated approach of de Jesus et al. (2019) and extends their study by providing a visual model of the CE transition paired with I4.0 tools, highlighting the need for concurrent technological and non-technological innovation.

6.2. Practical implications

The conceptual framework we propose also contributes to practice, benefits practitioners, addresses the urgency to act, and contributes to the SDGs. To inform the framework, this review investigated the practical adoption and benefits of I4.0 tools, such as blockchain, IoT, PSS and cloud manufacturing. The review has provided conceptual examples of AM and generally highlighted the role of intelligent goods and digitalization in the CE.

First, the conceptual model developed in this review could serve as a practical tool to facilitate a company's transition from a linear to circular business model and to identify the enabling role of I4.0, such as AM in design; blockchain in collaborations; virtual platforms, big data in service-based models; and IoT sensors in product lifecycle management and reverse flows. Therefore, businesses can build upon these examples and follow and test the framework to understand how they can implement and benefit from the adoption of technologies.

Second, this model brings attention to the complex system of interconnected factors among value chain characteristics, collaborations, closed-loop systems and product lifecycle management. The model speaks to business levels, but it encapsulates a more holistic, meso and macro level to show the overarching reach and influence of a CE–I4.0 transition. Therefore, the model warrants businesses to leave behind siloed solutions and it demonstrates that transition to a CE will require an orchestrated approach among more than one actor.

Lastly, the CE transition can be realized differently according to the context a business operates in. This speaks to the study of Bauwens et al. (2020), who conducted a scenario analysis of possible circular futures according to different national characteristics. They presented potential circular futures across high vs low tech innovations and centralized and decentralized governance. Therefore, depending on the context a business operates in, some elements could be prioritized over others. It is important to note that this study builds upon articles that investigated the waste, textile, footwear, manufacturing, automobile and electric-electronic and equipments industries and sectors and its findings might be more applicable in this context. However, the framework aims to generally address the transition process, the gradual adaptation to CE to design new models, fit the business environment, implement technologies (Carraresi and Bröring, 2021), tailor strategies and develop new skills accordingly to seek a competitive advantage (Lopes de Sousa Jabbour et al., 2019; Salvador et al., 2021b).

7. Conclusion and limitations

This SLR has conceptualized the CE–I4.0 epistemology through current literature, synthesizing and providing an overview of the CE transition process through a business model lens. Our framework depicts which directions businesses should innovate to and it pinpoints specific I4.0 tools that enable the elements of *service-based models, circular design, reverse flows, consumers and users, collaborations* and *product lifecycle management.*

This framework contributes by bringing together relevant sciential and business factors into a single study. Although there has been an increasing number of studies in the field of CE–I4.0 (Bjørnbet et al., 2021), investigating the interconnected nature of elements along the business transition process to a CE has not yet been fully understood and conceptualized. The framework shows the transition to a CE as a paradigm shift (Campbell-Johnston et al., 2019), which transcends siloed solutions and requires a holistic, *'embracing all'* approach and consideration of different stakeholder interest and expectations (Awan et al., 2021). With the proposed conceptual framework, we embrace a holistic approach, demonstrate which business elements influence each other and how within the same *'circular system'*, and we underline the role of specific I4.0 tools along this transition.

The limitations of the study are driven by the methodology, specifically the quality assessment guide. This review adopted the ABS (2021) guide to assess the quality of journals and include studies on this basis. Although the ABS guide offers a robust quality measurement of academic journals (Morris et al., 2009) and is often used in systematic literature reviews (Rojanakit et al., 2022), there are some criticism around the subjective adjustment of rankings and the explicit bias against several subject areas and in favour of business and management (Hoepner and Unerman, 2012). For instance, some examples of the reviewed articles included waste, manufacturing and automobile industries and sectors, but other industries that also implement circular solutions have not been featured, i.e., food, fashion and design. These industries could provide significant contributions and extend or add plausibly missing elements of the framework and show different design, technology and reverse flow solutions.

This study adopted an SLR approach; however, this methodology, the conceptual model and research outcomes could be further developed to overcome some of its limitations and to address missing pieces. Next we propose potential future research avenues referring to methodology, emerging and developed countries, technology, and entrepreneurship.

8. Future research

8.1. Methodology

First, most of the reviewed papers investigated CE implementation at a micro, company level. However, as Parida et al. (2019) highlight, a CE business model transformation goes beyond a company's boundaries and could impact an ecosystem, which is why the CE promotes a network-centric system configuration (Carraresi and Bröring, 2021). This was also proposed in the conceptual transition model developed in this review. Therefore, from a methodological perspective, more holistic, meso- or macro-level studies could advance the understanding of transition processes at a higher level, true to the closed-loop nature of the CE. This could imply the involvement of more stakeholders in future studies, such as producers, manufacturers, suppliers, designers as well as consumers within the same supply or value chain, which would enable an understanding of different perspectives of the 'same' transition process (yet distinct parts) and the type and nature of relationships among stakeholders. In this regard, Blomsma et al. (2019) define the different nature of relationships across circular strategies as hierarchical, trade-off and synergies. A future study, in a comparable manner, could address the interconnected relationships across business elements and confirm or extend the transition model proposed in this study. A potential research question could be: *how does a company's CE transition affect the transition processes and strategies of others in its close ecosystem?*

In addition, our framework only shows six elements as part of the circular business model. This could be further extended, and certain elements can be added, for example, by integrating an institutional level, the role of government and institutions. Therefore, as a future research avenue, we suggest the assessment of our conceptual framework to test its relevance in different industries but also analyse how different levels of analysis impact our theorization.

Another methodological aspect is the adoption and analysis of a theoretical lens. Across the reviewed articles, some specified a theoretical lens, but there was no evident theoretical approach to analyse the CE transition (Fig. 3). Therefore, there is an opportunity to advance the theoretical considerations of the CE transition process. Future research could investigate transition theories to see how they reflect the complexity and interconnected nature of circular business models (Markard et al., 2012). This could also contribute to better defining CE processes and reducing the ambiguity in the field (Bjørnbet et al., 2021).

8.2. Context

The CE transformation process is context- and industry specific (Bauwens et al., 2020; Chauhan et al., 2022), dynamic and based upon a degree of maturity or circularity (Ünal and Shao, 2019), which requires different strategies and business models. This warrants future research to analyse more empirical cases in diverse contexts to understand how a company's position would impact these strategies and further requirements. For example, future research could look at the case of multinationals and global corporations, who hold a strategic place to promote change, as they could put pressure on other companies in their ecosystems, such as manufacturers or producers, to adopt similar CE principles. Therefore, a future study investigating multinationals that have incorporated CE principles could contribute to a better understanding of the CE transition of multinational and global chains at meso or macro levels.

Moreover, the multinational perspective raises another important question and challenge, specifically the role of institutions and the differences between emerging and developed economies. For example, this review highlighted an interesting paradox regarding the prominent dynamic relationship of design and returned products (Birkel and Müller, 2021; Franco, 2019), which could be an interesting future research avenue. Presumably, if a multinational company plans to become circular in its processes, their decisions and strategic direction would also relate to design techniques and, as such, would impact the design phase; this might take place in an emerging economy, given the global presence of supply chains and operations of large companies. Similarly, developing a reserve infrastructure could also extend beyond country borders and imply the involvement and reliance on an emerging economy and increase the issues related to uncertainties and supply chain bottlenecks. Therefore, future research can analyse the differences between emerging and developed economies in CE transitions and the adoption of technologies where emerging economies are at an institutional disadvantage (Gedam et al., 2021; Torres de Oliveira et al., 2020). It would be interesting to investigate the paradox mentioned before in terms of any tensions that may arise between developed and emerging economies due to the difference in their environments and also how these emerging economies can be incentivized (Nag et al., 2021) to adopt CE principles into their design elements and/or to contribute to the reverse flow of a global chain. Also, the role of intermediaries and non-market strategies while investigating emerging economies is another potential research field (Torres de Oliveira et al., 2020).

8.3. Technology

This review investigated the role of I4.0 technologies, but many articles only discuss digitalization and offer digital solutions at theoretical levels (Kerin and Pham, 2019; Narayan and Tidström, 2020; Unruh, 2018). However, the offered benefits have not yet been practically justified or realized. Therefore, future empirical research could involve a detailed analysis of each I4.0 tool to understand when its adoption is more justified in some processes (and therefore test the proposed model) or whether there are different conditions and transition stages that require different technologies. For example, as suggested by Narayan and Tidström (2020), blockchain technology could improve cooperation in the CE and provide ways to create and manage connected CE networks. Nonetheless, these remain theoretical examples, and their justification and articulation in real life remain uncertain. Building upon this case, future research could investigate blockchain technology and its role in the holistic CE transition and potentially its relevance to enabling connections throughout closed-loop systems.

Another important aspect to consider is the different level and degrees of digitalization and their impact across transition processes. For example, the conceptual model proposed by this study investigates I4.0 as an enabler, but it is acknowledged that digitalization—or lack thereof—can also be the main barrier in the transition to a CE. Additionally, this review highlighted some trade-offs and barriers related to I4.0 technologies (Hina et al., 2022), in terms of security, risk, and data leakage. Therefore, future research could reflect on how differences in digitalization levels of a traditional business model contribute to the implementation of CE principles. In conjunction, a longitudinal study could provide insights into the changes in transformation in relation to the intensity of digitalization during a given period. This could also inform the reasons behind the slow adoption of I4.0.

8.4. Entrepreneurship

Lastly, the digitally-enabled CE transformation process is presented as a complex, context-specific, dynamically changing system. Dependent on others in an ecosystem (i.e., multinationals and/or other stakeholders) and potentially the type and level of digitalization, the transition processes could look different across businesses, as well as in emerging and developed countries. This review also noted the new roles within reverse flows, i.e., *facilitators*, *redistributors* and *doers*, to close the gap between suppliers and customers, but requirements and skills sets to establish these roles remain unclear (Bakker et al., 2021). Therefore, future research could analyse how entrepreneurs interpret and implement circular models, how they support CE and how entrepreneurship in changing and shaping the organization in light of digitalization. For example, Veleva and Bodkin (2018) focused on the collaboration between large corporations and small entrepreneurs and analysed their relationship in terms of resources and innovative ideas. They found that entrepreneurs play an important role in introducing innovative ideas but face financial barriers and resource constraints, which on the other hand, could be supported by established market players. Similar comparative studies are needed to identify mechanisms, barriers and enablers, triggers, antecedents and outcomes. Therefore, future research could investigate the entrepreneurial processes and analyse how corporate purpose and strategy are changing.

CRediT authorship contribution statement

Agnes Toth-Peter: Conceptualization, Methodology, Validation, Formal analysis, Visualization, Writing – original draft. **Rui Torres de Oliveira ,:** Supervision, Methodology, Validation, Writing – review & editing. **Shane Mathews:** Writing – review & editing. **Leonie Barner:** Writing – review & editing. **Sandra Figueira:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Two of the co-authors are also part of the guest editorial team of this special issue. Therefore, the manuscript will be handled by Professor Cecilia Villas Boas de Almeida.

Data availability

No data was used for the research described in the article.

Acknowledgment

This work was supported by an Australian Government Research Training Program Scholarship.

References

Acerbi, F., Taisch, M., 2020. A literature review on circular economy adoption in the manufacturing sector. J. Clean. Prod. 273 https://doi.org/10.1016/j.jclepro.2020.123086.
Agrawal, R., Wankhede, V.A., Kumar, A., Luthra, S., Huisingh, D., 2022. Progress and trends in integrating Industry 4.0 within Circular Economy: a comprehensive literature review and future research propositions [Article] Bus. Strat. Environ. 31 (1), 559–579. https://doi.org/10.1002/bse.2910. John Wiley & Sons, Inc).
Agrawal, V.V., Atasu, A., Van Wassenhove, L.N., 2019. Winter2019). OM forum—new opportunities for operations management research in sustainability. Manuf. Serv. Oper. Manag. 21 (1), 1–12. https://doi.org/10.1287/msom.2017.0699.
Ahmed, Y.A., Ahmad, M.N., Ahmad, N., Zakaria, N.H., 2019. Social media for knowledge-sharing: a systematic literature review. Telematics Inf. 37, 72–112. https://doi.org/10.1016/j.tele.2018.01.015.
Ajwani-Ramchandani, R., Figueira, S., Torres de Oliveira, R., Jha, S., 2021. Enhancing the circular and modified linear economy: the importance of blockchain for developing economies. Resour. Conserv. Recycl. 168, 105468 https://doi.org/10.1016/j.resconrec.2021.105468.
Ajwani-Ramchandani, R., Figueira, S., Torres de Oliveira, R., Jha, S., Ramchandani, A., Schuricht, L., 2021. Towards a circular economy for packaging waste by using new technologies: the case of large multinationals in emerging economies. J. Clean. Prod. 281 https://doi.org/10.1016/j.jclepro.2020.125139.
Antikainen, M., Uusitalo, T., Kivikytö-Reponen, P., 2018. Digitalisation as an enabler of circular economy. Procedia CIRP 73, 45–49. https://doi.org/10.1016/j.procir.2018.04.027.
Awan, U., Sroufe, R., Shahbaz, M., 2021. Industry 4.0 and the circular economy: a literature review and recommendations for future research [Article]. Bus. Strat. Environ. 30 (4), 2038–2060. https://doi.org/10.1002/bse.2731.
Aziz, N.A., Adnan, N.A.A., Wahab, D.A., Azman, A.H., 2021. Component design optimisation based on artificial intelligence in support of additive manufacturing repair and restoration: current status and future outlook for remanufacturing [Article]. J. Clean. Prod. 296 https://doi.org/10.1016/j.jclepro.2021.126401.
Bag, S., Gupta, S., Kumar, S., 2021. Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development [Article]. Int. J. Prod. Econ. https://doi.org/10.1016/j.ijpe.2020.107844.
Bag, S., Yadav, G., Dhamija, P., Kataria, K.K., 2021. Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: an empirical study [Article]. J. Clean. Prod. 281 https://doi.org/10.1016/j.jclepro.2020.125233.
Bai, C., Orzes, G., Sarkis, J., 2022. Exploring the impact of Industry 4.0 technologies on social sustainability through a circular economy approach [Article]. Ind. Market. Manag. 101, 176–190. https://doi.org/10.1016/j.indmarman.2021.12.004.
Bakker, C.A., Mugge, R., Boks, C., Oguchi, M., 2021. Understanding and managing product lifetimes in support of a circular economy. J. Clean. Prod. 279 https://doi.org/10.1016/j.jclepro.2020.123764.
Baldacchino, L., Ucbasaran, D., Cabantous, L., Lockett, A., 2015. Entrepreneurship research on intuition: a critical analysis and research agenda. Int. J. Magn. Reson. Imag. 17 (2), 212–231. https://doi.org/10.1111/ijmr.12056.
Bauwens, T., Hekkert, M., Kirchherr, J., 2020. Circular futures: what will they look like? Ecol. Econ. 175 https://doi.org/10.1016/j.ecolecon.2020.106703.
Belhadi, A., Kamble, S.S., Chiappetta Jabbour, C.J., Mani, V., Khan, S.A.R., Touriki, F.E., 2022. A self-assessment tool for evaluating the integration of circular economy and industry 4.0 principles in closed-loop supply chains [Article]. Int. J. Prod. Econ. https://doi.org/10.1016/j.ijpe.2021.108372.
Birkel, H., Müller, J.M., 2021. Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability – a systematic literature review. J. Clean. Prod. 289 https://doi.org/10.1016/j.jclepro.2020.125612.
Bjørnbet, M.M., Skaar, C., Fet, A.M., Schulte, K.Ø., 2021. Circular economy in manufacturing companies: a review of case study literature. J. Clean. Prod. 294 https://doi.org/10.1016/j.jclepro.2021.126268.

Blomsma, F., Brennan, G., 2017. The emergence of circular economy: a new framing around prolonging resource productivity. J. Ind. Ecol. 21 (3), 603–614. https://doi.org/10.1111/jiec.12603.

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D.C.A., Hildenbrand, J., Kristinsdottir, A.R., Kristoffersen, E., Shahbazi, S., Nielsen, K.D., Jönbrink, A.-K., Li, J., Wiik, C., McAloone, T.C., 2019. Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. J. Clean. Prod. 241 https://doi.org/10.1016/j.jclepro.2019.118271.

2016/07/03) Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33 (5), 308–320. https://doi.org/10.1080/21681015.2016.1172124.

Bressanelli, G., Pigosso, D.C.A., Saccani, N., Perona, M., 2021. Enablers, levers and benefits of circular economy in the electrical and electronic equipment supply chain: a literature review [article]. J. Clean. Prod. 298 https://doi.org/10.1016/j.jclepro.2021.126819.

Brown, P., Von Daniels, C., Bocken, N.M.P., Balkenende, A.R., 2021. A process model for collaboration in circular oriented innovation. J. Clean. Prod. 286 https://doi.org/10.1016/j.jclepro.2020.125499.

Caldera, H.T.S., Desha, C., Dawes, L., 2019. Evaluating the enablers and barriers for successful implementation of sustainable business practice in 'lean' SMEs. J. Clean. Prod. 218, 575–590. https://doi.org/10.1016/j.jclepro.2019.01.239.

Campbell-Johnston, K., Calisto Friant, M., Thapa, K., Lakerveld, D., Vermeulen, W.J.V., 2020. How circular is your tyre: experiences with extended producer responsibility from a circular economy perspective. J. Clean. Prod. 270 https://doi.org/10.1016/j.jclepro.2020.122042.

Campbell-Johnston, K., Cate, J.t., Elfering-Petrovic, M., Gupta, J., 2019. City level circular transitions: barriers and limits in amsterdam, utrecht and the hague. J. Clean. Prod. 235, 1232–1239. https://doi.org/10.1016/j.jclepro.2019.06.106.

Carraresi, L., Bröring, S., 2021. How does business model redesign foster resilience in emerging circular value chains? J. Clean. Prod. 289 https://doi.org/10.1016/j.jclepro.2021.125823.

Chari, A., Niedenzu, D., Despeisse, M., Machado, C.G., Azevedo, J.D., Boavida-Dias, R., Johansson, B., 2022. Dynamic Capabilities for Circular Manufacturing Supply Chains—Exploring the Role of Industry 4.0 and Resilience. Business Strategy and the Environment.

Chartered Association of Business Schools [ABS], 2021. Academic Journal Guide 2021. https://charteredabs.org/academic-journal-guide-2021/.

Chauhan, C., Parida, V., Dhir, A., 2022. Linking circular economy and digitalisation technologies: a systematic literature review of past achievements and future promises. Technol. Forecast. Soc. Change 177, 121508.

Chen, D., Ma, Y., Yang, R., Sun, J., 2021. Performance analysis of China's regional circular economy from the perspective of circular structure [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.126644.

Christofi, M., Vrontis, D., Thrassou, A., Shams, S.M.R., 2019. Triggering technological innovation through cross-border mergers and acquisitions: a micro-foundational perspective. Technol. Forecast. Soc. Change 146, 148–166. https://doi.org/10.1016/j.techfore.2019.05.026.

Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Łuniewska, M., Ruggieri, A., Ioppolo, G., 2021. Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0. Bus. Strat. Environ. https://doi.org/10.1002/bse.2801 [Article].

Dahmani, N., Benhida, K., Belhadi, A., Kamble, S., Elfezazi, S., Jauhar, S.K., 2021. Smart circular product design strategies towards eco-effective production systems: a lean eco-design industry 4.0 framework [Article]. J. Clean. Prod. 320 https://doi.org/10.1016/j.jclepro.2021.128847.

De Giovanni, P., 2022. Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives. Int. J. Oper. Prod. Manag. 42 (7), 959–994. https://doi.org/10.1108/IJOPM-07-2021-0445.

de Jesus, A., Antunes, P., Santos, R., Mendonça, S., 2019. Eco-innovation pathways to a circular economy: envisioning priorities through a Delphi approach. J. Clean. Prod. 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049.

de Jesus, A., Mendonça, S., 2018. Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. Ecol. Econ. 145, 75–89. https://doi.org/10.1016/j.ecolecon.2017.08.001.

Díaz-Chao, Á., Ficapal-Cusí, P., Torrent-Sellens, J., 2021. Environmental assets, industry 4.0 technologies and firm performance in Spain: a dynamic capabilities path to reward sustainability. J. Clean. Prod. 281 https://doi.org/10.1016/j.jclepro.2020.125264.

Di Maria, E., De Marchi, V., Galeazzo, A., 2022. Industry 4.0 technologies and circular economy: the mediating role of supply chain integration [Article]. Bus. Strat. Environ. (John Wiley & Sons, Inc) 31 (2), 619–632. https://doi.org/10.1002/bse.2940.

Dutta, P., Talaulikar, S., Xavier, V., Kapoor, S., 2021. Fostering reverse logistics in India by prominent barrier identification and strategy implementation to promote circular economy. J. Clean. Prod. 294 https://doi.org/10.1016/j.jclepro.2021.126241.

Dwivedi, A., Moktadir, M.A., Jabbour, C.J.C., de Carvalho, D.E., 2021. Integrating the Circular Economy and Industry 4.0 for Sustainable Development: Implications for Responsible Footwear Production in a Big Data-Driven World. Technological Forecasting and Social Change, 121335.

Ellen MacArthur Foundation, 2017. The Circular Economy in Detail. Retrieved April 4 from. https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail.

Ellen MacArthur Foundation, McKinsey Center for Business and Environment, 2015. GROWTH WITHIN: A CIRCULAR ECONOMY VISION FOR A COMPETITIVE EUROPE. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf.

Ertz, M., Sun, S., Boily, E., Kubiat, P., Quenum, G.G.Y., 2022. How transitioning to Industry 4.0 promotes circular product lifetimes [Article]. Ind. Market. Manag. 101, 125–140. https://doi.org/10.1016/j.indmarman.2021.11.014.

Fatimah, Y.A., Govindan, K., Murniningsih, R., Setiawan, A., 2020. Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: a case study of Indonesia. J. Clean. Prod. 269 https://doi.org/10.1016/j.jclepro.2020.122263.

Franco, M.A., 2019. A system dynamics approach to product design and business model strategies for the circular economy. J. Clean. Prod. 241 https://doi.org/10.1016/j.jclepro.2019.118327.

Frishammar, J., Parida, V., 2019. Circular business model transformation: a roadmap for incumbent firms. Calif. Manag. Rev. 61 (2), 5–29. https://doi.org/10.1177/0008125618811926.

Gedam, V.V., Raut, R.D., Lopes de Sousa Jabbour, A.B., Tanksale, A.N., Narkhede, B.E., 2021. Circular economy practices in a developing economy: barriers to be defeated [Article]. J. Clean. Prod. 311 https://doi.org/10.1016/j.jclepro.2021.127670.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048.

Ghisellini, P., Ulgiati, S., 2020. Circular economy transition in Italy. Achievements, perspectives and constraints. J. Clean. Prod. 243 https://doi.org/10.1016/j.jclepro.2019.118360.

Hankammer, S., Brenk, S., Fabry, H., Nordemann, A., Piller, F.T., 2019. Towards circular business models: identifying consumer needs based on the jobs-to-be-done theory. J. Clean. Prod. 231, 341–358. https://doi.org/10.1016/j.jclepro.2019.05.165.

Harvey, C., Kelly, A., Morris, H., Rowlinson, M., 2010. The association of business schools. Acad. J. Q. Guide 4, 1–15.

Hettiarachchi, B.D., Brandenburg, M., Seuring, S., 2022. Connecting additive manufacturing to circular economy implementation strategies: links, contingencies and causal loops [Article]. Int. J. Prod. Econ. 246 https://doi.org/10.1016/j.ijpe.2022.108414.

Heyes, G., Sharmina, M., Mendoza, J.M.F., Gallego-Schmid, A., Azapagic, A., 2018. Developing and implementing circular economy business models in service-oriented technology companies. J. Clean. Prod. 177, 621–632. https://doi.org/10.1016/j.jclepro.2017.12.168.

Hina, M., Chauhan, C., Kaur, P., Kraus, S., Dhir, A., 2022. Drivers and barriers of circular economy business models: where we are now, and where we are heading [Article]. J. Clean. Prod. 333 https://doi.org/10.1016/j.jclepro.2021.130049.

Hoepner, A.G., Unerman, J., 2012. Explicit and implicit subject bias in the ABS journal quality guide. Account. Educ. 21 (1), 3–15.

Hoffmann, B.S., de Simone Morais, J., Teodoro, P.F., 2020. Life cycle assessment of innovative circular business models for modern cloth diapers. J. Clean. Prod. 249 https://doi.org/10.1016/j.jclepro.2019.119364.

Spring2018) Hopkinson, P., Zils, M., Hawkins, P., Roper, S., 2018. Managing a complex global circular economy business model: opportunities and challenges [article]. Calif. Manag. Rev. 60 (3), 71–94. https://doi.org/10.1177/0008125618764692.

Ingemarsdotter, E., Kambanou, M.L., Jamsin, E., Sakao, T., Balkenende, R., 2021. Challenges and solutions in condition-based maintenance implementation - a multiple case study [Article]. J. Clean. Prod. 296 https://doi.org/10.1016/j.jclepro.2021.126420.

Inigo, E.A., Blok, V., 2019. Strengthening the socio-ethical foundations of the circular economy: lessons from responsible research and innovation. J. Clean. Prod. 233, 280–291. https://doi.org/10.1016/j.jclepro.2019.06.053.

Johannsdottir, L., 2014. Transforming the linear insurance business model to a closed-loop insurance model: a case study of Nordic non-life insurers. J. Clean. Prod. 83, 341–355. https://doi.org/10.1016/j.jclepro.2014.07.010.

Jones, P., Wynn, M.G., 2019. The circular economy, natural capital and resilience in tourism and hospitality [Article]. Int. J. Contemp. Hospit. Manag. 31 (6), 2544–2563. https://doi.org/10.1108/IJCHM-05-2018-0370.

Kayikci, Y., Kazancoglu, Y., Gozacan-Chase, N., Lafci, C., Batista, L., 2022. Assessing smart circular supply chain readiness and maturity level of small and medium-sized enterprises [Article]. J. Bus. Res. https://doi.org/10.1016/j.jbusres.2022.05.042.

Kerin, M., Pham, D.T., 2019. A review of emerging industry 4.0 technologies in remanufacturing. J. Clean. Prod. 237 https://doi.org/10.1016/j.jclepro.2019.117805.

Khan, I.S., Ahmad, M.O., Majava, J., 2021. Industry 4.0 and sustainable development: a systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives [Article]. J. Clean. Prod. 297 https://doi.org/10.1016/j.jclepro.2021.126655.

Khan, M.A., Mittal, S., West, S., Wuest, T., 2018. Review on upgradability – a product lifetime extension strategy in the context of product service systems. J. Clean. Prod. 204, 1154–1168. https://doi.org/10.1016/j.jclepro.2018.08.329.

Khan, S.A.R., Razzaq, A., Yu, Z., Miller, S., 2021. Industry 4.0 and circular economy practices: a new era business strategies for environmental sustainability [Article]. Bus. Strat. Environ. 30 (8), 4001–4014. https://doi.org/10.1002/bse.2853.

Konietzko, J., Baldassarre, B., Brown, P., Bocken, N., Hultink, E.J., 2020. Circular business model experimentation: demystifying assumptions. J. Clean. Prod. 277 https://doi.org/10.1016/j.jclepro.2020.122596.

Konietzko, J., Bocken, N., Hultink, E.J., 2020. Circular ecosystem innovation: an initial set of principles [Article]. J. Clean. Prod. 253 https://doi.org/10.1016/j.jclepro.2019.119942.

Kouhizadeh, M., Zhu, Q., Sarkis, J., 2020. Blockchain and the circular economy: potential tensions and critical reflections from practice [Article]. Prod. Plann. Control. https://doi.org/10.1080/09537287.2019.1695925.

Kristoffersen, E., Blomsma, F., Mikalef, P., Li, J., 2020. The smart circular economy: a digital-enabled circular strategies framework for manufacturing companies. J. Bus. Res. 120, 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044.

Kumar, R., Singh, R.K., Dwivedi, Y.K., 2020. Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: analysis of challenges. J. Clean. Prod. 275 https://doi.org/10.1016/j.jclepro.2020.124063.

Lahane, S., Kant, R., Shankar, R., 2020. Circular supply chain management: a state-of-art review and future opportunities. J. Clean. Prod. 258 https://doi.org/10.1016/j.jclepro.2020.120859.

Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B., Uriarte-Gallastegi, N., 2021. Exploring the influence of industry 4.0 technologies on the circular economy [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.128944.

Lieder, M., Asif, F.M.A., Rashid, A., 2020. A choice behavior experiment with circular business models using machine learning and simulation modeling. J. Clean. Prod. 258 https://doi.org/10.1016/j.jclepro.2020.120894.

Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042.

Lopes de Sousa Jabbour, A.B., Rojas Luiz, J.V., Rojas Luiz, O., Jabbour, C.J.C., Ndubisi, N.O., Caldeira de Oliveira, J.H., Junior, F.H., 2019. Circular economy business models and operations management [Article]. J. Clean. Prod. 235, 1525–1539. https://doi.org/10.1016/j.jclepro.2019.06.349.

Lopes de Sousa Jabbour, A.B., Jabbour, C.J.C., Godinho Filho, M., Roubaud, D., 2018. Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann. Oper. Res. 270 (1–2), 273–286. https://doi.org/10.1007/s10479-018-2772-8.

Lu, J., Ren, L., Zhang, C., Rong, D., Ahmed, R.R., Streimikis, J., 2020. Modified Carroll's pyramid of corporate social responsibility to enhance organizational performance of SMEs industry. J. Clean. Prod. 271 https://doi.org/10.1016/j.jclepro.2020.122456.

Luoma, P., Penttinen, E., Tapio, P., Toppinen, A., 2022. Future images of data in circular economy for textiles. Technol. Forecast. Soc. Change. https://doi.org/10.1016/j.techfore.2022.121859 [Article].

Ma, S., Zhang, Y., Liu, Y., Yang, H., Lv, J., Ren, S., 2020. Data-driven sustainable intelligent manufacturing based on demand response for energy-intensive industries. J. Clean. Prod. 274 https://doi.org/10.1016/j.jclepro.2020.123155.

Maitre-Ekern, E., 2021. Re-thinking producer responsibility for a sustainable circular economy from extended producer responsibility to pre-market producer responsibility. J. Clean. Prod. 286 https://doi.org/10.1016/j.jclepro.2020.125454.

Mangla, S.K., Luthra, S., Mishra, N., Singh, A., Rana, N.P., Dora, M., Dwivedi, Y., 2018. Barriers to effective circular supply chain management in a developing country context. Prod. Plann. Control 29 (6), 551–569. https://doi.org/10.1080/09537287.2018.1449265.

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Pol. 41 (6), 955–967.

Massaro, M., Secinaro, S., Dal Mas, F., Brescia, V., Calandra, D., 2021. Industry 4.0 and circular economy: an exploratory analysis of academic and practitioners' perspectives [Article]. Bus. Strat. Environ. 30 (2), 1213–1231. https://doi.org/10.1002/bse.2680.

Mastos, T.D., Nizamis, A., Terzi, S., Gkortzis, D., Papadopoulos, A., Tsagkalidis, N., Ioannidis, D., Votis, K., Tzovaras, D., 2021. Introducing an application of an industry 4.0 solution for circular supply chain management [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.126886.

Morris, H., Harvey, C., Kelly, A., 2009. Journal Rankings and the ABS Journal Quality Guide. Management Decision.

Nag, U., Sharma, S.K., Govindan, K., 2021. Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy [Article]. J. Clean. Prod. 319 https://doi.org/10.1016/j.jclepro.2021.128629.

Narayan, R., Tidström, A., 2020. Tokenizing coopetition in a blockchain for a transition to circular economy. J. Clean. Prod. 263 https://doi.org/10.1016/j.jclepro.2020.121437.

Neligan, A., Baumgartner, R.J., Geissdoerfer, M., Schöggl, J.P., 2022. Circular Disruption: Digitalisation as a Driver of Circular Economy Business Models, 1. Business Strategy & the Environment. https://doi.org/10.1002/bse.3100 [Article].

Nobre, G.C., Tavares, E., 2020. Assessing the role of big data and the Internet of Things on the transition to circular economy: Part I : an extension of the ReSOLVE framework proposal through a literature review. Johnson Matthey Technol. Rev. 64 (1), 19–31. https://doi.org/10.1595/205651319X15643932870488.

Okorie, O., Salonitis, K., Charnley, F., Moreno, M., Turner, C., Tiwari, A., 2018. Digitisation and the circular economy: a review of current research and future trends. Energies 11 (11), 3009. https://doi.org/10.3390/en11113009.

Pagoropoulos, A., Pigosso, D.C.A., McAloone, T.C., 2017. The emergent role of digital technologies in the circular economy: a review. Procedia CIRP 64, 19–24. https://doi.org/10.1016/j.procir.2017.02.047.

Palmié, M., Boehm, J., Lekkas, C.-K., Parida, V., Wincent, J., Gassmann, O., 2021. Circular business model implementation: design choices, orchestration strategies, and transition pathways for resource-sharing solutions. J. Clean. Prod. 280 https://doi.org/10.1016/j.jclepro.2020.124399.

Parida, V., Burström, T., Visnjic, I., Wincent, J., 2019. Orchestrating industrial ecosystem in circular economy: a two-stage transformation model for large manufacturing companies. J. Bus. Res. 101, 715–725. https://doi.org/10.1016/j.jbusres.2019.01.006.

Pialot, O., Millet, D., Bisiaux, J., 2017. Upgradable PSS": clarifying a new concept of sustainable consumption/production based on upgradablility. J. Clean. Prod. 141, 538–550. https://doi.org/10.1016/j.jclepro.2016.08.161.

Pinheiro, M.A.P., Jugend, D., Lopes de Sousa Jabbour, A.B., Chiappetta Jabbour, C.J., Latan, H., 2022. Circular economy-based new products and company performance: the role of stakeholders and Industry 4.0 technologies. Bus. Strat. Environ. https://doi.org/10.1002/bse.2905 [Article].

Piscitelli, G., Ferazzoli, A., Petrillo, A., Cioffi, R., Parmentola, A., Travaglioni, M., 2020. Circular economy models in the industry 4.0 era: a review of the last decade. Procedia Manuf. 42, 227–234. https://doi.org/10.1016/j.promfg.2020.02.074.

Pizzi, S., Corbo, L., Caputo, A., 2021. Fintech and SMEs sustainable business models: reflections and considerations for a circular economy. J. Clean. Prod. 281 https://doi.org/10.1016/j.jclepro.2020.125217.

Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A., 2017. Circular Economy: Measuring Innovation in the Product Chain. PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf.

Rajala, R., Hakanen, E., Mattila, J., Seppälä, T., Westerlund, M., 2018. How do intelligent goods shape closed-loop systems? Calif. Manag. Rev. 60 (3), 20–44. https://doi.org/10.1177/0008125618759685.

Rajput, S., Singh, S.P., 2019. Connecting circular economy and industry 4.0 [Article]. Int. J. Inf. Manag. https://doi.org/10.1016/j.ijinfomgt.2019.03.002.

Rajput, S., Singh, S.P., 2020. Industry 4.0 Model for circular economy and cleaner production [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2020.123853.

Rojanakit, P., Torres de Oliveira, R., Dulleck, U., 2022. The sharing economy: a critical review and research agenda. J. Bus. Res. 139, 1317–1334. https://doi.org/10.1016/j.jbusres.2021.10.045.

Rosa, P., Sassanelli, C., Terzi, S., 2019. Towards Circular Business Models: a systematic literature review on classification frameworks and archetypes. J. Clean. Prod. 236 https://doi.org/10.1016/j.jclepro.2019.117696.

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., Terzi, S., 2020. Assessing relations between Circular Economy and Industry 4.0: a systematic literature review. Int. J. Prod. Res. 58 (6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896.

Salvador, R., Barros, M.V., Freire, F., Halog, A., Piekarski, C.M., De Francisco, A.C., 2021. Circular economy strategies on business modelling: identifying the greatest influences [Article]. J. Clean. Prod. 299 https://doi.org/10.1016/j.jclepro.2021.126918.

Salvador, R., Puglieri, F.N., Halog, A., Andrade, F.G.d., Piekarski, C.M., De Francisco, A. C., 2021. Key aspects for designing business models for a circular bioeconomy. J. Clean. Prod. 278 https://doi.org/10.1016/j.jclepro.2020.124341.

Schwanholz, J., Leipold, S., 2020. Sharing for a circular economy? an analysis of digital sharing platforms' principles and business models. J. Clean. Prod. 269 https://doi.org/10.1016/j.jclepro.2020.122327.

Selvefors, A., Rexfelt, O., Renström, S., Strömberg, H., 2019. Use to use – a user perspective on product circularity. J. Clean. Prod. 223, 1014–1028. https://doi.org/10.1016/j.jclepro.2019.03.117.

Shayganmehr, M., Kumar, A., Garza-Reyes, J.A., Moktadir, M.A., 2021. Industry 4.0 enablers for a cleaner production and circular economy within the context of business ethics: a study in a developing country [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2020.125280.

Stahel, W., 2010. The Performance Economy, 2010, second ed. Palgrave Macmillan UK. https://doi.org/10.1057/9780230274907.

Torres de Oliveira, R., Indulska, M., Zalan, T., 2020. Blockchain and the multinational enterprise: progress, challenges and future research avenues. Rev. Int. Bus.Strat. 30 (2), 145–161.

Tozanlı, Ö., Kongar, E., Gupta, S.M., 2020. Trade-in-to-upgrade as a marketing strategy in disassembly-to-order systems at the edge of blockchain technology. Int. J. Prod. Res. 58 (23), 7183–7200. https://doi.org/10.1080/00207543.2020.1712489.

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14 (3), 207–222. https://doi.org/10.1111/1467-8551.00375.

Tseng, M.-L., Tan, R.R., Chiu, A.S.F., Chien, C.-F., Kuo, T.C., 2018. Circular economy meets industry 4.0: can big data drive industrial symbiosis? Resour. Conserv. Recycl. 131, 146–147. https://doi.org/10.1016/j.resconrec.2017.12.028.

Tunn, V.S.C., Bocken, N.M.P., van den Hende, E.A., Schoormans, J.P.L., 2019. Business models for sustainable consumption in the circular economy: an expert study. J. Clean. Prod. 212, 324–333. https://doi.org/10.1016/j.jclepro.2018.11.290.

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., Valkokari, P., 2019. Unlocking circular business: a framework of barriers and drivers. J. Clean. Prod. 212, 90–98. https://doi.org/10.1016/j.jclepro.2018.11.202.

United Nations, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf.

United Nations. (n.d.). Ensure Sustainable Consumption and Production Patterns. https://sdgs.un.org/goals/goal12.

Unruh, G., 2018. Circular economy, 3D printing, and the biosphere rules. Calif. Manag. Rev. 60 (3), 95–111. https://doi.org/10.1177/0008125618759684.

Upadhyay, A., Mukhuty, S., Kumar, V., Kazancoglu, Y., 2021. Blockchain technology and the circular economy: implications for sustainability and social responsibility [Article]. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2021.126130.

Ünal, E., Shao, J., 2019. A taxonomy of circular economy implementation strategies for manufacturing firms: analysis of 391 cradle-to-cradle products. J. Clean. Prod. 212, 754–765. https://doi.org/10.1016/j.jclepro.2018.11.291.

Veleva, V., Bodkin, G., 2018. Corporate-entrepreneur collaborations to advance a circular economy. J. Clean. Prod. 188, 20–37. https://doi.org/10.1016/j.jclepro.2018.03.196.

Vinante, C., Sacco, P., Orzes, G., Borgianni, Y., 2021. Circular economy metrics: literature review and company-level classification framework. J. Clean. Prod. 288 https://doi.org/10.1016/j.jclepro.2020.125090.

Wang, N., Ren, S., Liu, Y., Yang, M., Wang, J., Huisingh, D., 2020. An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode. J. Clean. Prod. 277 https://doi.org/10.1016/j.jclepro.2020.123365.

Whalen, K.A., 2019. Three circular business models that extend product value and their contribution to resource efficiency. J. Clean. Prod. 226, 1128–1137. https://doi.org/10.1016/j.jclepro.2019.03.128.

Wilson, J., Arshed, N., Shaw, E., Pret, T., 2017. Expanding the domain of festival research: a review and research agenda. Int. J. Magn. Reson. Imag. 19 (2), 195–213. https://doi.org/10.1111/ijmr.12093.

Xiao, Y., Watson, M., 2019. Guidance on conducting a systematic literature review. J. Plann. Educ. Res. 39 (1), 93–112. https://doi.org/10.1177/0739456X17723971.

Yadav, G., Luthra, S., Jakhar, S.K., Mangla, S.K., Rai, D.P., 2020. A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: an automotive case. J. Clean. Prod. 254 https://doi.org/10.1016/j.jclepro.2020.120112.

Yu, Z., Khan, S.A.R., Umar, M., 2022. Circular economy practices and industry 4.0 technologies: a strategic move of automobile industry [Article]. Bus. Strat. Environ. 31 (3), 796–809. https://doi.org/10.1002/bse.2918. John Wiley & Sons, Inc).

Zheng, T., Ardolino, M., Bacchetti, A., Perona, M., 2021. The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. Int. J. Prod. Res. 59 (6), 1922–1954.