Resources, Conservation & Recycling Advances 20 (2023) 200189

Contents lists available at ScienceDirect

Resources, Conservation & Recycling Advances

journal homepage: www.sciencedirect.com/journal/Resources-Conservation-and-Recycling-Advances

Digital technologies for resource loop redesign in circular supply chains: A systematic literature review

Giovanni Francesco Massari *, Raffaele Nacchiero, Ilaria Giannoccaro

Department of Mechanics, Mathematics, and Management, Politecnico di Bari, Italy

ARTICLE INFO

Keywords:
Circular supply chains
Digital technologies
Closing
Slowing
Narrowing
Intensifying
Dematerializing

ABSTRACT

Multiple stakeholders are responsible for the supply chain redesign for the transition to Circular Supply Chains (CSCs). Despite it has been demonstrated that certain supply chain (SC) capabilities and Digital Technologies (DTs) can play a determinant role on the design of specific CSC archetypes, current knowledge remains still sparse. To fill this research gap, we conduct a Systematic Literature Review. Results show that specific SC capabilities are required for *closing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *slowing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *narrowing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *intensifying* (intra-sectorial collaboration, inter-sectorial collaboration, flexibility, visibility), and dematerializing (inter-sectorial collaboration, visibility) resource streams. In a similar way, the combination of DTs is proven useful for closing (BDA, AI, AM, IoT, BC, CC), slowing (BDA, AI, AM, IoT, BC, CC), narrowing (BDA, AI, AM, IoT, BC), intensifying (AM, IoT, BC, CC), and dematerializing (BDA, AI, AM, IoT, BC, CC) resource streams.

1. Introduction

To speed up transition towards "circular" industries represents today imperative as demonstrated by the European Union Circular Economy action plan. This requires the complete rethink and redesign of the prevailing linear supply chains (SCs), according to the Circular Economy (CE) principles, toward the development of Circular Supply Chains (CSCs).

CSCs are *self-sustained* systems designed to operate in a "*restorative and regenerative*" way by recapturing residual value from by-products, extracting new value from end-of-life resources, extending product life for as long as feasible, and increasing resource efficiency (Farooque et al., 2019; Genovese et al., 2017; Nasir et al., 2017; Lahane et al., 2020).

The transition to CSCs is successfully achieved through the collective adoption of Circular Business Models (CBMs) (Bocken et al., 2016; Mangla et al., 2018; Sehnem et al., 2019) by multiple stakeholders i.e., those internal and external to the original SC boundaries. CBMs transform the prevailing linear resource management along the SC by *closing, slowing, intensifying, narrowing*, and *dematerializing* resource streams (Bocken et al., 2016), thus leading to specific CSC archetypes. Despite less investigated by scholars, we argue the current classification is important since it helps to distinguish the SC capabilities, useful for the design of a specific CSC archetype, and the Digital Technologies (DTs) enhancing them. Our argumentation finds strong support in literature. Numerous studies have emphasized the need to establish not only local information sharing i.e., upstream and downstream, but also across different SC sectors. For example, while intra-sectorial collaboration has proven useful to implement resource efficiency and eco-design strategies (González-Sánchez et al., 2020; Hazen et al., 2020), inter-sectorial collaboration results to be vital for performing industrial symbiosis operations (Batista et al., 2018; González-Sánchez et al., 2020; Herczeg et al., 2018; Leising et al., 2018; Luthra et al., 2022) and enabling cross-sector relationships sharing economy environments (González-Sánchez et al., 2020; Luthra et al., 2022). Flexibility is particularly relevant for the adoption of green customization and sustainable manufacturing practices (Bai et al., 2020); on the contrary, visibility represents a fundamental capability to enable servitization and access-over ownerships models (Kouhizadeh et al., 2019; Sharma et al., 2020).

Overall, the findings relating SC capabilities to the specific CSC archetype remain still sparse and fragmented.

So far, multiple review frameworks have been developed to summarize the vital role of DTs on the implementation of CE strategies (see

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* Corresponding author.
E-mail address: giovannifrancesco.massari@poliba.it (G.F. Massari).

https://doi.org/10.1016/j.rcradv.2023.200189

the review studies by Ada et al., 2021; Furstenau et al., 2020; Hassoun et al., 2023; Rejeb and Appolloni, 2022; Yu et al., 2022), CBM dimensions (see the review studies by Taddei et al., 2022), resource efficiency and other sustainable practices (see the review studies by Bag and Pretorius, 2022; de Oliveira Neto et al., 2023; Inamdar et al., 2020; Huang et al., 2012; Jabbour et al., 2020; Khan et al., 2021a,b; Kouhizadeh et al. 2020; Niaki and Nonino, 2016; Ocampo et al., 2018; Rusch et al., 2023; Shojaei et al., 2021; Mohd Yusuf et al., 2019), without relating them to a specific CSC archetype.

To fill this research gap, we conduct a Systematic Literature Review (SLR) to address two interrelated research questions (RQs):

1. Which SC capability is required for the design of a specific CSC archetype?
2. Which DT enables the design of a specific CSC archetype?

The paper is organized as follows. In Section 2, we present the research context regarding CSCs. Then, Section 3 provides the description of the research methodology, including material collection, refinement, and analysis. Section 4 is devoted respectively to presenting the results of the content analysis to address both the RQs. While Section 5 includes the discussion and suggestions for future studies, implications and limitations are discussed in Section 6.

2. Research context

2.1. Circular supply chains

CE represents the most promising solution to drive the sustainable development while replacing the current take-make-use-dispose (linear) paradigm. The primary suggestion of CE is to decouple the economic growth from natural resource usage and environmental degradation (UNEP, 2018). This prescribes systems to operate in a self- "restorative and regenerative" (EMF, 2013) way toward a more efficient use of resource value for as long as possible, and elimination of waste (Farooque et al., 2019; Kirchherr et al., 2017). This is made possible by the purposeful redesign of business models and industrial processes to enable the implementation of CE strategies for value creation and delivery e.g., eco-design, maintenance, repair, reuse, refurbish, remanufacture, recycle, and those for value proposition e.g., long-lasting product design, product-as-a-service (Montag, 2022).

These disruptive changes require the involvement and integration of multiple stakeholders upstream and downstream the different value chains are necessary i.e., the design of CSCs.

In literature, scholars defined CSCs in different ways all, however, converging to the integration of CE thinking on all the SC stages (Geissdoerfer et al., 2018) and the implementation of CE strategies by the involved stakeholders (Farooque et al., 2019; Genovese et al., 2017; Nasir et al., 2017). For example, while Genovese et al. (2017) focus on CSCs "diverting used products from being discarded as waste through the recovery of value and reused in production of secondary products", Nasir et al. (2017) define CSCs as those "enabling products at the end of their life cycle to re-enter the supply chain as a production input through recycling, re-usage or remanufacturing", and Mangla et al. (2018) as a "restorative production system, where resources, enter an infinite loop of reuse, remanufacturing and recycling".

CSCs thus configure as self-regenerative ecosystems integrating a high number and variety of stakeholders in a connected network to extract new value from end-of-life resources, extend product life, and increase resource efficiency ideally toward zero-waste operating conditions (Lahane et al., 2020). In CSCs, resources move along the forward SCs, originally separated, and the reverse SCs. Through reverse SCs, resources circulate back to firms belonging to the original SC sector, via closed loops, or to different sectors or directly to natural eco-system, via open loops (De Angelis et al., 2018). In this way, the waste outputs from a SC become input resources for another SC e.g., recycled bottles can become construction material (Farooque et al., 2019; Scheel and Vasquez, 2013), unusable tires can play as bitumen for asphalting future roads, or even cooking waste oils can be used to produce biodiesel (Genovese et al., 2017), and so on. Due to the additional regenerative dimension, CSCs profoundly differ from green and reverse SCs already including the restorative dimension through the implementation of green practices along the value chain (e.g., green purchasing, green distribution, eco-design) to reduce pollution and emissions, and strategies for material recovery. CSCs also extend the boundaries of closed-loop SCs, given that resources circulate back to all the stakeholders from the surrounding natural and industrial ecosystems, rather than only to those belonging to the original manufacturer (Guide and VanWassenhove, 2006). On one hand, a closed-loop SC takes materials back to the original manufacturer only (Guide and VanWassenhove, 2006), thus limiting the extent of recovered value and still generating substantial amounts of waste as it is rarely feasible to reuse/recycle all unwanted items within the same SC (Moula et al., 2017). On the other, a circular supply takes materials back to the original SC through close loops, or to third parties through open loops. Here, waste residuals from a process/SC become resources for another process/SC e.g., recycled bottles can become construction material (Farooque et al., 2019; Scheel and Vasquez, 2013), unusable tires can play as bitumen for asphalting future roads, or even cooking waste oils can be used to produce biodiesel (Farooque et al., 2019; Genovese et al., 2017).

2.2. Classifying the archetypes of CSCs

Different CSC archetypes can emerge from *closing, slowing, narrowing, intensifying,* and *dematerializing* resource loops.

The principle of *closing* resource loops has the purpose of creating new value through the collection of non-functional products at their end-of-life stage and transformation into new valuable resources, through recycling processes, and/or reusing them by partnering industries (Bocken et al., 2016; De Angelis et al., 2018; EMF and McKinsey & Co., 2012). Biological and nontoxic products can turn back safely to the biosphere without any need for processing (EMF and McKinsey & Co., 2012). CSCs for closing resource loops are characterized by long and structured networks of multiple interdependencies that facilitate the flow of the products that need to be transformed. An interesting example is the SC of Plastics for Change which recycles waste plastics to generate new plastic materials (rPET, rPP, rHDPE and rLDPE) that can be returned to the market. It is characterized by a long cycle consisting of the following players: the waste picker which recovers and collects the recovered plastic; the scrap shop that performs a first separation of the recovered material; the franchise aggregator that performs a second separation of the material; the granule producer that transforms waste into plastic granules; the manufacturer who converts the granules obtained into usable packaging; the brand that obtains the packaging and places it on the consumer market. The principle of *slowing* resource loops aims at extending product value and material circulation by remanufacturing products, parts, and components, and prolonging product life by designing for durability and repair. Maintenance ensures prolonged durability through the reuse for the same purpose with either little or no change; refurbishment/remanufacturing involve replacements of some relevant components and recovery of components to be used within a new manufacturing process respectively (EMF and McKinsey & Co., 2012). CSCs for slowing resource loops tend to adopt a multi-localized and inhomogeneous structure to allow the formation of constantly new interactions with suppliers and customers. The Italian social enterprise Quid recovers the textile inventories of major brands and other companies to transform them into new products. CSC of Quid is characterized by several short cycles with numerous different companies, such as Berto Industria Tessile or Ermenegildo Zegna, from which it receives donated fabrics or clothes and for which it redesigns and produces new fine clothes ready for the market after the upgrade.

The principle of *narrowing* resource loops entails increasing resource efficiency by reducing the use material and energy for manufacturing products, through eco-design (Mendoza et al., 2017). CSCs for narrowing resource loops include a centralized trend that enhances the operations of upstream suppliers, from which economic and environmental benefits spread throughout the SC. Over the last decade, the FCA Group (now part of Stellantis) has launched a long redesign campaign from an ecological perspective that has led to the development of a narrowing-oriented CSC. The company has focused on eco-design choices aimed at reducing vehicle weights (new design solutions with plastic use, solutions for metal replacement, etc.), increasing recyclability and eliminating critical substances (e.g., heavy metals)

Intensifying and *dematerializing* resource loops aims at providing the services to satisfy user requests, thus replacing the needs for own physical product. Recovering value from products and services can be achieved by increasing materials' durability and maximizing resource efficiency. To this regard, designing for modularity, reparability, upgradability, and recyclability increases product/service circulation within the whole system. Value recovery depends also on the used resources e.g., materials and energy. CSCs for intensifying resource loops elaborate structural SC models around resource sharing centers that allow a more value-intensive use phase for circulating materials and products. For example, Cohealo's CSC is based on the operation of a digital platform that allows hospitals to share their medical equipment and services, thus maximizing resource utilization and improving the quality of patient care. CSCs for dematerializing resource loops represent perhaps the most complex and disruptive case of circular reconversion of the traditional SC model, as they aim to completely transform the downstream flow to customers with a service system that eliminates the disadvantages deriving from the ownership-acquisition by the customers, increasing the longevity of the products themselves. An example of this CSC model is represented by Floow2 that is the first business-to-business sharing market that allows companies and institutions to share overcapacity of staff equipment, knowledge, and skills. Users can register for free on the platform and attendees pay a subscription to advertise their equipment on the platform, providing a revenue stream for Floow2. It facilitates the sharing of overcapacity of company equipment and the skills and knowledge of staff who are underutilized half the time, making them transparent and negotiable on their platform. Floow2 considers its platform as a win-win solution for businesses because companies that have committed capital investment upfront on equipment can increase their revenue by using the platform to rent any undistributed equipment and personnel at full capacity.

According to Gupta et al. (2019) and other scholars, SC firms are required to improve current capabilities and strategies to reconfigure and reorganize operations, structures, and models around the CE needs (Hart, 1995; Wu et al., 2013; Lacy and Rutqvist, 2015). To this regard, the ongoing Fourth Industrial Revolution is providing organizations and companies with enhanced capabilities.

3. Research methodology

In this study, a SLR approach is adopted as research methodology to address the research questions above presented. SLR differs from other review approaches e.g., narrative literature reviews, for a number of reasons. First, a SLR is driven by specific RQs formulated based on existing literature gaps, which in turn define the search strategy. Second, a SLR follows a specific protocol consisting of consecutive stages and guiding the entire review process. Third, a SLR aims at identifying and summarizing relevant conceptual contents rather than providing a general analysis of a few studies addressing the problem under investigation. In this study, we plan to conduct a SLR starting from the two RQs reported in the Introduction which aim to summarize the SC capabilities and DTs useful for the design of a specific CSC archetype.

We follow the three-phase SLR protocol, and the corresponding guidelines provided by Denyer and Tranfield (2009); Rosa et al. (2020); Smart et al. (2017). Therefore, in the following, the three phases of material collection, material refinement, and content analysis are described. This approach has been recently adopted by other studies on the CSC field (Calzolari et al., 2022; Taddei et al., 2022).

3.1. Material collection

Material collection represents the first stage of a SLR process. Out of the three most-relevant scientific databases i.e., Scopus, Google Scholar, and Web of Science, we preferred Scopus for multiple reasons. It is considered the largest citation and abstract database covering peer-reviewed journals from a wide range of fields (Agrawal et al., 2022; Sharma et al., 2020), even broader than that of Web of Science. We excluded Google Scholar because of its low data quality, which raises questions about its suitability for research (Meho and Yang, 2007; Mongeon and Paul-Hus, 2016). We excluded Web of Science as providing access to older sources (Farooque et al., 2019), which in our case is not considered advantageous as we are investigating a recent phenomenon.

The keywords selection has been conducted through a focus team composed by three researchers operating in the field of CSC management and SC digitalization. Initially, the researchers selected the keywords related to DTs and CSCs based on their expertise. Subsequently, keyword selection was validated and refined by comparing our keywords with those adopted in other review studies with a similar research purpose (Gebhardt et al., 2022; Taddei et al., 2022). Once selected, the keywords referring to "Industry 4.0 and Digital Technologies" theme were combined through AND Boolean operator with each keyword referring to "Circular Supply Chain" theme (see Table 1), thus creating multiple search strings. The latter were used to search for articles published in peer-reviewed scientific journals and conference proceedings. The search was first conducted in July 2020 producing 518 results, and then updated in June 2023 producing 299 new results. Thus, in total, we collected 817 records.

3.2. Material refinement

In order to select the final sample and focus on research papers that are close to the topic under investigation, material refinement through title, abstract, and full-text assessment was conducted. Both the assessments were conducted by two authors independently and, in case of disagreement on inclusion-exclusion decision, also by the third author (Centobelli et al., 2017; Centobelli et al., 2020). During title and abstract assessment, the authors excluded the articles out of topic i.e., not focusing on the adoption of DTs neither for CE strategy implementation on the SC level nor for resource management in sustainable, green, closed-loop, reverse, and CSCs. After title and abstract assessment, 253 records were excluded. During the full-text assessment, the authors

Table 1
The keywords used to create the search strings.

Topic	Selected keywords
Industry 4.0 and digital technologies	("big data" OR "data analytics" OR "BDA" OR "Big Data Analytics" OR "blockchain" OR "augmented realit*" OR "virtual realit" OR "digital twin" OR "digital twin simulation" OR "IoT" OR "Internet of Thing" OR "Industrial Internet of Thing" OR "Industrial IoT" OR "Industry 4.0" OR "I4.0" OR "additive manufacturing" OR "3D printing" OR "3D-printing" OR "3D-print*" OR "3D print*" OR "robotic process automation" OR "robot*" OR "cloud-based computing" OR "cloud computing" OR "cloud" OR "artificial intelligence" OR "AI")
Circular supply chain	("circular supply chain" OR "green supply chain" OR "closed loop supply chain" OR "open loop supply chain" OR "reverse supply chain" OR "circular supply network" OR "green supply network" OR "closed loop supply network" OR "open loop supply network" OR "reverse supply network")

included papers with high thematic consistency. In particular, the articles without an explicit focus on the CSC archetypes, those revising general trends and opportunities of DT implementation for CSCs, those mentioning the influence of DTs for SC redesign just into conclusions and implications, or those investigating a too-technical aspect concerning the development of a certain DT, or even those explaining DT adoption in linear SCs with only few recommendations for CSCs, were excluded. After full-text assessment, 174 records were considered eligible for content analyses. Table A1 (see Appendix A) reports the complete list of records used for result reporting. Fig. 1 reports the SLR process.

3.3. *Descriptive analysis*

This section aims at reporting a descriptive analysis of the final samples in terms of their distribution over time (see Fig. 2) and across scientific journals (see Table 2). Temporal distribution helps understanding whether and how scholars' interest has increased over the course of years. Fig. 2 shows a significant increase in the number of published articles only since 2015.

Table A1 shows that the 174 articles were published into 70 scientific journals covering multiple and overlapping disciplines, meaning how multidisciplinary the investigated topic is. Based on the number of published articles and citations (see Fig. 3), the ten most relevant journals are Journal of Cleaner Production (25 articles and 2872 citations), Sustainability (14 articles and 776 citations), International Journal of Production Research (11 articles and 3137 citations), Resources, Conservation and Recycling (9 articles and 1298 citations), International Journal of Production Economics (8 articles and 2110 citations), Computers and Industrial Engineering (7 articles and 348 citations), Business Strategy and the Environment (6 articles and 201 citations), Technological Forecasting and Social Change (5 articles and 1087 citations), International Journal of Advanced Manufacturing Technology (4 articles and 363 citations), and International Journal of Logistics Management (4 articles and 292 citations).

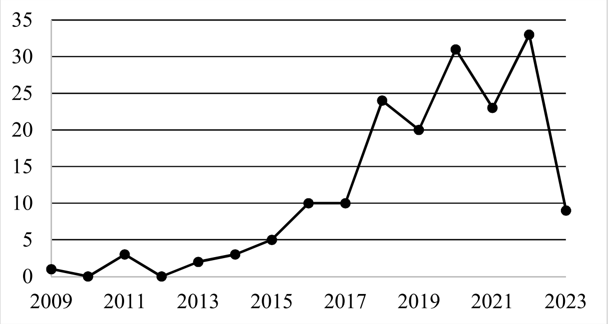

Fig. 2. Temporal evolution of scientific publications.

4. Results

The results of content analyses are organized to address the RQs we

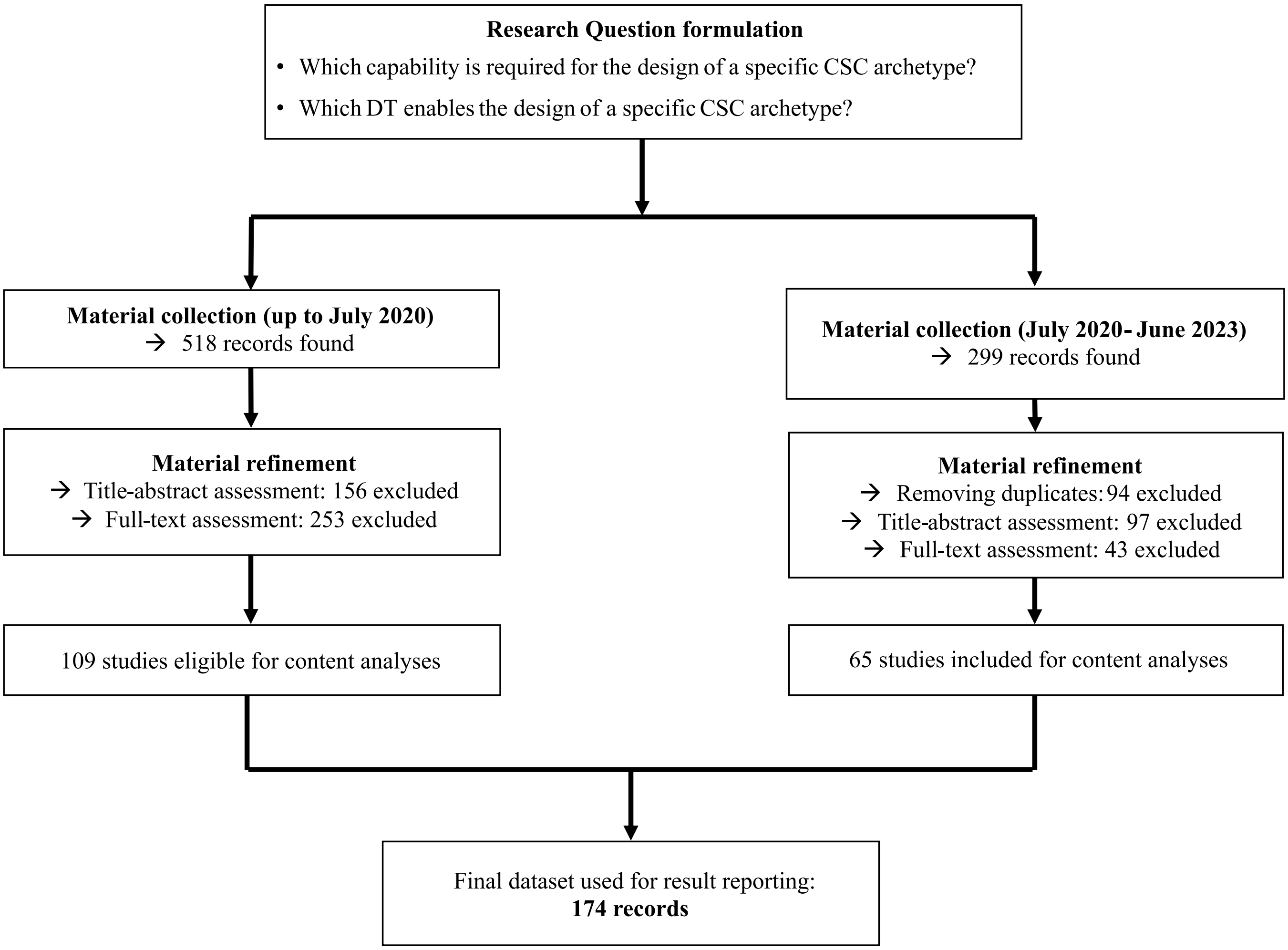

Fig. 1. The SLR process.

Table 2

SC Capabilities required for the design of specific CSC archetypes.

SC capability	CSC archetype				
	Closing	Slowing	Narrowing	Intensifying	Dematerializing
Intra-sectorial collaboration	(Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Centobelli et al., 2022; Chidepatil et al., 2020; De Giovanni, 2022; Del Giudice et al., 2020; Dev et al., 2020; Gong et al., 2022a; Kayikci et al., 2021; Kayikci et al., 2022; Kouhizadeh et al., 2019; Leising et al., 2018; Ma et al., 2022; Mastos et al., 2020; Mastos et al., 2021; Miemczyk et al., 2016; Mosallanezhad et al., 2023; Raut et al., 2019; Wang et al., 2020a; Xiang and Xu, 2020)	(Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Centobelli et al., 2022; De Giovanni, 2022; Dev et al., 2020; Hazen et al., 2020; Kayikci et al., 2021; Ma and Mo, 2023; Miemczyk et al., 2016; Sharma et al., 2020; Wang et al., 2016; Xiang and Xu, 2020; Zheng et al., 2021)	(Aarikka-Stenroos et al., 2022; Agrawal et al., 2021; Allaoui et al., 2019; Benzidia et al., 2021; De Vass et al., 2021; Di Vaio and Varriale, 2020; Ghadge et al., 2022; Khanfar et al., 2021; Kouhizadeh and Sarkis, 2018; Kouhizadeh et al., 2019; Khan et al., 2023; Lu et al., 2018; Luthra et al., 2020; Ma et al., 2018; Mageto, 2021; Manupati et al., 2020; Melander and Pazirandeh, 2019; Paliwal et al., 2020; Rane and Thakker, 2020; Rane et al., 2021; Raut et al., 2019; Saberi et al., 2019; Tan et al., 2020; Tseng et al., 2019; Umar et al., 2022; Wang et al., 2016; Wang et al., 2020a;; Zheng et al., 2021)	(Abideen et al., 2021; Del Giudice et al., 2020; Hazen et al., 2020; Kayikci et al., 2021; Kayikci et al., 2022; Kouhizadeh et al., 2019; Leising et al., 2018; Ma and Mo, 2023; Sharma et al., 2020; Wang et al., 2020a)	
Inter-sectorial collaboration	(Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Gong et al., 2022b; Herczeg et al., 2018; Luthra et al., 2022; Miemczyk et al., 2016)	(Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Kalverkamp, 2018; Luthra et al., 2022; Miemczyk et al., 2016; Wang et al., 2016)	(Aarikka-Stenroos et al., 2022; Khan et al., 2023; Luthra et al., 2022;Melander and Pazirandeh, 2019)	(Pazaitis et al., 2017)	(Pazaitis et al., 2017)
Flexibility	(Bai et al., 2020; Bai and Sarkis, 2013; Dev et al., 2020; Hazen et al., 2020; Kayikci et al., 2021; Miemczyk et al., 2016)	(Bai and Sarkis, 2013; Dev et al., 2020; Garrido-Hidalgo et al., 2020; Kayikci et al., 2021; Lahrour and Brissaud, 2018; Miemczyk et al., 2016; Wang et al., 2016)	(Agrawal et al., 2021; Bai et al., 2020; Di Vaio and Varriale, 2020; Gebler et al., 2014; Hazen et al., 2020; Khan et al., 2023; Luthra et al., 2020; Tseng et al., 2019)	(Bai et al., 2020; Hazen et al., 2020; Kayikci et al., 2021; Mattos Nascimento et al., 2019; Zanetti et al., 2016)	
Visibility	(Abideen et al., 2021; Centobelli et al., 2022; Chidepatil et al., 2020; De Giovanni, 2022; Delpla et al., 2022; Dev et al., 2020; Esmaeilian et al., 2020; Gong et al., 2022a; Gong et al., 2022b; Kouhizadeh et al., 2019; Kouhizadeh and Sarkis, 2018; Ma et al., 2022; Mastos et al., 2020; Mastos et al., 2021; Mosallanezhad et al., 2023; Prajapati et al., 2022; Wang et al., 2020a; Xiang and Xu, 2020)	(Abideen et al., 2021; Centobelli et al., 2022; De Giovanni, 2022; Dev et al., 2020; Garrido-Hidalgo et al., 2020; Ma and Mo, 2023; Prajapati et al., 2022; Wang et al., 2016; Xiang and Xu, 2020)	(Agrawal et al., 2021; Allaoui et al., 2019; De Vass et al., 2021; Di Vaio and Varriale, 2020; Esmaeilian et al., 2020; Ghadge et al., 2022; Gholizadeh et al., 2020; Han and Rani, 2022; Hazen et al., 2020; Kayikci et al., 2022; Kazancoglu et al., 2023; Khanfar et al., 2021; Kouhizadeh et al., 2019; Kouhizadeh and Sarkis, 2018; Khan et al., 2023; Luthra et al., 2020; Ma et al., 2018; Mageto, 2021; Melander and Pazirandeh, 2019; Paliwal et al., 2020; Ramirez-Peña et al., 2020; Saberi et al., 2019; Shukla and Tiwari, 2017; Tan et al., 2020; Tseng et al., 2019; Umar et al., 2022; Wang et al., 2016; Wang et al., 2020a)	(Abideen et al., 2021; Benzidia et al., 2021; Delpla et al., 2022; Hazen et al., 2020; Ma and Mo, 2023; Wang et al., 2020a)	(Kouhizadeh et al., 2019; Sharma et al., 2020)
Traceability	(Mastos et al., 2021; Prajapati et al., 2022; Rane and Thakker, 2020)	(Prajapati et al., 2022; Varriale et al., 2020)	(Anastasiadis et al., 2022; Agrawal et al., 2021; Ghadge et al., 2022; Khanfar et al., 2021; Kouhizadeh and Sarkis, 2018; Kshetri, 2021; Han and Rani, 2022; Manupati et al., 2020; Paliwal et al., 2020; Rane and Thakker, 2020; Saberi et al., 2019; Wang et al., 2020a; Yachai et al., 2021)		

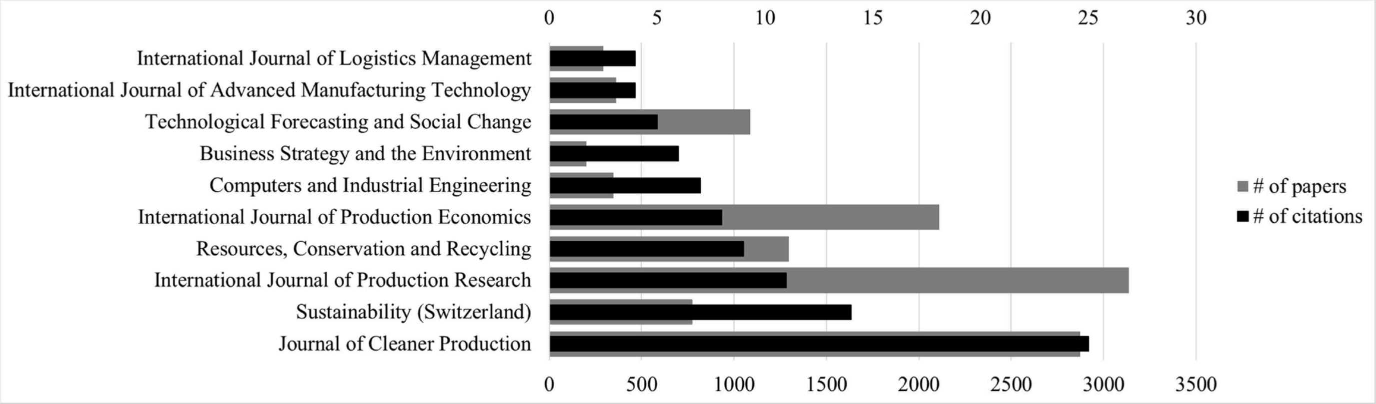

Fig. 3. The ten most-relevant scientific journals based on the number of published articles and the number of citations.

posed. To this aim, the authors performed a thematic classification of the final set of samples (see Table A2) by progressively grouping them into two groups: the first including the studies investigating the SC capabilities useful for the design of a certain CSC archetype, while the second including those studying the DTs affecting the design of a certain CSC archetype. In the following, the results of content analyses are presented.

4.1. *Which SC capability is required for the design of a certain CSC archetype?*

Table 2 reports the results of content analyses describing the SC capabilities necessary for the design of certain CSC archetypes. These include intra-sectorial collaboration, inter-sectorial collaboration, flexibility, visibility, and traceability.

4.1.1. *Intra-sectorial collaboration*

In SC management literature, collaboration allows two or more firms working together for pursuing common goals. A key enabler of SC collaboration is information-sharing since allowing the involved firms to carry out joint decision-making activities, technological integration for new product and process development, logistic integration etc. (de Leeuw and Fransoo, 2009; Kumar and van Dissel, 1996). Intra-sectorial collaboration i.e., that established between two or more firms belonging to the same SC sector, is a prerequisite for *closing, slowing, narrowing*, and *intensifying* resource loops, thereby affecting the design of the corresponding CSC archetypes. 20 studies (11.5 %) have explained how collaborations are exploited for *closing* resource loops. Most-relevant cases include the development of collaborative approaches between waste management operators and suppliers via e.g., trust-based relationships, supplier integration, digital platforms, and coordination mechanisms between key areas of reverse logistics, to jointly carry out recycling operations on end-of-life resources i.e., spare parts, waste materials (steel, plastics, textile, carpet etc.), Covid-19 pandemic wastes, by-products, and scraps, materials for construction and building (Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Centobelli et al., 2022; Chidepatil et al., 2020; De Giovanni, 2022; Del Giudice et al., 2020; Dev et al., 2020; Kayikci et al., 2021; Leising et al., 2018; Ma et al., 2022; Mastos et al., 2020; Miemczyk et al., 2016; Mosallanezhad et al., 2023; Xiang and Xu, 2020), to implement waste-to-energy strategies (Kayikci et al., 2022; Mastos et al., 2021; Raut et al., 2019), product deletion practices (Kouhizadeh et al., 2019), and even to improve the performance of recycling processes (Wang et al., 2020a; Gong et al., 2022a; Mastos et al., 2021). According to 13 studies (7.5 %), dyadic and triadic collaborations established between suppliers, manufacturers, recycler logistic providers, and waste collectors/recyclers are crucial for *slowing* resource loops as enabling part remanufacturing (Dev et al., 2020; Xiang and Xu, 2020; Zheng et al., 2021), the implementation of "Design for X" strategies i.e., for longevity, disassembly, standardization (Aarikka-Stenroos et al., 2022), and modularity (Hazen et al., 2020), the design of take-back and reverse logistic systems for product-return flow management and control (Aarikka-Stenroos et al., 2022; Abideen et al., 2021; Centobelli et al., 2022; De Giovanni, 2022; Kayikci et al., 2021; Ma and Mo, 2023; Miemczyk et al., 2016; Sharma et al., 2020). Demand-related information can be shared through distribution-to-consumer collaborations and used to understand and predict the consumers' desirability of circular products manufactured with recycled materials (Hazen et al., 2020), as in the case of textile and carpet (Miemczyk et al., 2016). The importance of intra-sectorial collaboration for *narrowing* resource loops is emphasized by 28 (16.1 %) studies, as demonstrated by the increased resource efficiency for sustainable manufacturing processes (Aarikka-Stenroos et al., 2022; Agrawal et al., 2021; Allaoui et al., 2019; De Vass et al., 2021; Khanfar et al., 2021; Luthra et al., 2020; Paliwal et al., 2020; Saberi et al., 2019; Wang et al., 2016), the reduced use of materials, energy, water, and other critical resources (Luthra et al., 2020; Melander and Pazirandeh, 2019; Ma et al., 2018; Zheng et al., 2021), the reduced emission and pollution for green and decarbonized logistics operations (Benzidia et al., 2021; Di Vaio and Varriale, 2020; Hazen et al., 2020; Kouhizadeh and Sarkis, 2018; Ma et al., 2018; Manupati et al., 2020; Melander and Pazirandeh, 2019; Tan et al., 2020), the enhanced sustainable/green material procurement (Ghadge et al., 2022; Khan et al., 2023; Kouhizadeh and Sarkis, 2018; Lu et al., 2018; Mageto, 2021; Rane and Thakker, 2020; Tseng et al., 2019; Umar et al., 2022), sustainable product life-cycle management (Wang et al., 2020a), and green product-design strategies (Rane et al., 2021). The results from 10 studies (4.6 %) provide evidence on how *intensifying* resource loops is influenced by the collaboration between suppliers, manufacturers, and warehousers since enabling the reuse of products and components (Abideen et al., 2021; Del Giudice et al., 2020) e.g., end-of-life garments in the fast-fashion industry (Wang et al., 2020a), textile materials and furniture components (Kayikci et al., 2022), part reuse in the service part maintenance industry (Ma and Mo, 2023), construction materials (Leising et al., 2018), or the reuse of soil through collaborative construction project planning and design (Aarikka-Stenroos et al., 2022), and other materials as packaging materials e.g., pallets or discarded plastics. In some contexts, competing firms collaborate, through the adoption of digital platforms for information-sharing, to foster the use of shared resources e.g., industrial equipment, and services, e.g., logistics. In the construction industry, such coopetition model is exploited by focal companies with its competitors (e.g., awning producers) for the reuse of soil (Aarikka-Stenroos et al., 2022). Additional benefits obtained through collaboration-based platforms involving suppliers and manufacturers regard product servitization (Sharma et al., 2020), while customer engagement enhance the optimal utilization of durable goods in terms of rental, leasing, and reuse practices, (Hazen et al., 2020;

Kouhizadeh et al., 2019).

4.1.2. Inter-sectorial collaboration

Out of intra-sectorial collaborations, CSCs demand inter-sectorial collaborations so called as involving two or more firms beyond the original sector boundaries (Gebhardt et al., 2022; González-Sánchez et al., 2020; Govindan and Hasanagic, 2018), thus operating along different SCs. Through them, a large number of by-products, end-of-life resources, and recovered materials become useful for different industrial sectors, thus enabling the design of certain CSCs i.e., those obtained by *closing, slowing,* and *narrowing* resource loops. Among the analysed records, 6 of them (3.4 %) analysed the collaborations useful for *closing* resource loops. Key advantages are realized through industrial symbiosis dyadic relationships and within IS networks (Herczeg et al., 2018) which permit specialized organic fertilizer producers turning coffee waste into compost to be sold to rice producers (Aarikka-Stenroos et al., 2022), developing innovative metal-to-organic recycling processes (Aarikka-Stenroos et al., 2022), recycling plastic debris into secondary raw materials (Gong et al., 2022b), replacing unsustainable substances with secondary raw materials as occurring through the collaboration between carpet manufacturers and a global polymer material recycler (Miemczyk et al., 2016), or between composite textile recyclers and cross-industry manufacturers (Abideen et al., 2021; Luthra et al., 2022; Miemczyk et al., 2016). Other 6 articles (3.4%) found that *slowing* resource loops is enhanced through external collaborations e.g., those between manufacturers and R&D companies for products' upgradability, or those in the form of a consortium involving textile and furniture producers exploiting new markets for recycled fabric (Aarikka-Stenroos et al., 2022; Miemczyk et al., 2016), or even those between manufacturers and independent market actors i.e., dismantlers and brokers, who act as middlemen players to provide used components for remanufacturing through open-loops and, thus, slowing resource loops (Abideen et al., 2021; Luthra et al., 2022; Kalverkamp, 2018; Wang et al., 2016). 4 studies emphasize the need of inter-sectorial collaboration for *narrowing* resource loops given the enhanced energy efficiency (Melander and Pazirandeh, 2019), and emission reduction due to close collaboration with strategic customers (Aarikka-Stenroos et al., 2022; Khan et al., 2023; Luthra et al., 2022; Melander and Pazirandeh, 2019). Finally, the functioning of the matchmaking platforms for sharing economy imply novel forms of collaborations between cross-sector firms and with sharing platform owners to use external resources obtaining economic benefits from *intensifying* and *dematerializing* resource loops (Pazaitis et al., 2017).

4.1.3. Flexibility

In SC management literature, flexibility refers to the SC ability to timely react to market dynamics with minimal loss on performance (Blome et al., 2014) and, more recently, to face with greening requirements and environmental regulations (Bai and Sarkis, 2018), while simultaneously seeking to achieve CE goals (Bag and Rahman, 2023). Flexibility is declined into different types and constructs according to the SC stage in which it is studied e.g., manufacturing and product flexibility, procurement flexibility, logistics flexibility (Bai et al., 2020). The analysed studies provide evidence that flexibility plays as prerequisite for the design of certain CSC archetypes i.e., those obtained by *closing, slowing, intensifying,* and *narrowing* resource loops. 6 studies (3.44 %) argue that procurement flexibility (Bai et al., 2020; Miemczyk et al., 2016), resource flexibility (Dev et al., 2020; Kayikci et al., 2021) and reverse logistics flexibility (Bai and Sarkis, 2013; Hazen et al., 2020) are required for *closing* resource loops since allowing an effective and timely reconfiguration of forward and reverse resource flows, and solving complex sourcing issues e.g., finding the right mix of virgin and secondary raw materials or the continuous improvement of recycling processes (Miemczyk et al., 2016). 7 studies (4 %) instead investigated reverse logistics flexibility as a critical capability for *slowing* resource loops by enabling the recall of second-hand and remanufactured/repaired products via tack-back systems (Bai and Sarkis, 2018; Dev et al., 2020; Kayikci et al., 2021; Lahrour and Brissaud, 2018) e.g., lithium-ion electric vehicle battery packs (Garrido-Hidalgo et al., 2020), increasing the control on closed-loop operations (Miemczyk et al., 2016; Wang et al., 2016); while product flexibility as a required capability for high-value adding activities for the completion of "Design for X" practices. 8 studies (4.6 %) argue that for *narrowing* resource loops it is necessary to have product flexibility e.g., for green customization, reverse logistic and manufacturing flexibility to reduce environmental penalties and protection costs, control and reduce waste streams as occurring in the air and automotive industry (Di Vaio and Varriale, 2020; Luthra et al., 2020), and quickly respond to pollution accidents (Bai et al., 2020), and reverse logistics flexibility to integrate innovative and sustainable transportation modes to serve last mile delivery e.g., bicycle couriers and drone aircrafts (Hazen et al., 2020). High degree of SC flexibility ensures an optimal use of resources and a reduced power consumption (Garrido-Hidalgo et al., 2020). Combining procurement, manufacturing and logistic flexibility enable firms to timely select, alter, and change the structure of first tier green suppliers, with whom developing green products (Gebler et al., 2014; Khan et al., 2023; Tseng et al., 2019). The results from 5 studies (2.87 %) provide evidence that *intensifying* resource loops is enhanced by resource flexibility promoting the reuse of waste and water (Kayikci et al., 2021) as well as material and energy (Bai et al., 2020). Flexible customer service management is found to extend the lifecycle of durable goods promoting optimal utilization of durable goods in terms of rental, leasing, and reuse practices. (i.e., via "sharing economy" practices) (Hazen et al., 2020). The design of CSCs by intensifying resource loops is enhanced through the adoption of flexible service-based processes, with specific regard to home printing, rapid prototyping, Tool/equipment rental and sharing consortia, topological optimization, and other relying on Additive Manufacturing technologies (Mattos Nascimento et al., 2019; Zanetti et al., 2016).

4.1.4. Visibility

In SC management literature, visibility is defined as the ability to access and share relevant information across the SC (Barratt and Barratt, 2011; Caridi et al., 2014; Goswami et al., 2013). The analysed studies provide evidence on how relevant visibility is for the design of all CSC archetypes. According to 18 studies (10.3 %), visibility is a key prerequisite for *closing* resource loops given the enhanced reverse recycling processes (Centobelli et al., 2022; Chidepatil et al., 2020; Delpla et al., 2022; Gong et al., 2022b; Kouhizadeh and Sarkis, 2018; Mastos et al., 2020; Mastos et al., 2021; Prajapati et al., 2022), better integration of downstream companies into recycling operations (Gong et al., 2022a), resource recovery strategies and reverse logistic processes (Abideen et al., 2021; Dev et al., 2020; Kouhizadeh et al., 2019; Mosallanezhad et al., 2023; Xiang and Xu, 2020), and the improved performance of recycling and channels (De Giovanni, 2022). Product life-cycle information increase the recyclability of materials since incentivizing individuals to participate in deposit-based recycling programs (Esmaeilian et al., 2020; Wang et al., 2020a) as observed e.g., in fast-fashion industry (Wang et al., 2020a). The presence of false information and/or the lack of visibility in the recycling process leads consumers not really understanding the value of recycled products, thus decreasing their level of trust toward recycling process, the manufacturers' willingness to recycle (Ma et al., 2022). On the contrary, increasing visibility of recycling channels e.g., among wood waste producers, improves the efficiency of waste management operations while providing the involved actors with new business opportunities in the waste-to-energy marketplace (Mastos et al., 2021). *Slowing* resource loops requires visibility into product return flows and customer's behavior e.g., perception of repaired/refurbished/remanufactured products. According to 9 studies (5.17 %), visibility impact the success of remanufacturing channels as observed in the context of lithium-ion electric vehicle battery packs (De Giovanni, 2022; Dev et al., 2020;

Garrido-Hidalgo et al., 2020) and other kind of reverse omnichannels e.g., repair (Abideen et al., 2021), and virtual closed-loop SC in e-commerce context (Prajapati et al., 2022). Visibility enables companies to visualize service part maintenance and timely decide which item(s) can be refurbished without incurring in excessive costs of recovery operations (Centobelli et al., 2022; Ma and Mo, 2023; Wang et al., 2016; Xiang and Xu, 2020). Based on 28 studies (16.09 %), visibility plays as prerequisite for *narrowing* resource loops. Product life-cycle visibility is fundamental to save energy (Esmaeilian et al., 2020) within each SC stage so reducing environmental pollution (Paliwal et al., 2020; Saberi et al., 2019; Tan et al., 2020), to reduce emissions during logistic operations (Gholizadeh et al., 2020; Hazen et al., 2020; Kouhizadeh et al., 2019; Ma et al. 2018; Melander and Pazirandeh, 2019; Tan et al., 2020), to design resource-efficient manufacturing processes (Agrawal et al., 2021; De Vass et al., 2021; Ghadge et al., 2022; Han and Rani, 2022; Khan et al., 2023; Ramirez-Peña et al., 2020; Tseng et al., 2019; Wang et al., 2016) e.g., in the automotive industry (Kazancoglu et al., 2023) and air traffic operations (Di Vaio and Varriale, 2020), to design resource-efficient and sustainable procurement processes (Allaoui et al., 2019; Kouhizadeh and Sarkis, 2018; Luthra et al., 2020; Shukla and Tiwari, 2017; Umar et al., 2022). For example, the energy consumption can be recorded, analyzed, and evaluated, and energy conversion and recycling can be calculated throughout the product life cycle. All the data on consumption and output emissions can be readily shared and integrated to evaluate the environmental performance of a product life cycle, the very essence of ecosystem quality management (Wang et al., 2020a). Through the adoption of DTs as Big Data Analytics and Blockchain, manufacturers can monitor and optimize resource consumption, reduce gas emissions, trace and measure the carbon footprint of each product by sharing accurate and authentic information and enhancing visibility (Khanfar et al., 2021; Mageto, 2021); or even track the source of raw materials and produced products, the amount of energy used in their production, the source of the energy (renewable and non-renewable) used through their life cycle can be traced to their sources (Kayikci et al., 2022). 6 studies (3.4 %) argue that visibility is determinant for *intensifying* resource loops since improving suppliers' commitment toward an increased use of recovered materials and reused products (Benzidia et al., 2021). Product transparency and visibility improves the efficacy of return management processes (Hazen et al., 2020), by increasing the opportunity for reuse as observed in the case of e.g., garments by fast-fashion industry actors (Abideen et al., 2021; Wang et al., 2020a), electronic components of EOL smartphones (Delpla et al., 2022), service parts maintenance (Ma and Mo, 2023). Finally, 2 studies (1.15 %) investigated visibility as key prerequisite for *dematerializing* resource loops since fostering product deletion (Kouhizadeh et al., 2019; Sharma et al., 2020). Having visible, accurate, and reliable information related to shared products and service provide companies with increased knowledge on products' locations, quality during the entire life-cycle, thus increasing the opportunity to trace and analyze reusability, performance, and durability of products and identify those products to be deleted from the portfolio, due to poor sharing value, high durability issues points of failure (Kouhizadeh et al., 2019).

4.1.5. Traceability

Finally, SC traceability is investigated as key determinant for the design of CSCs. It in fact allows *closing, slowing*, and *narrowing* resource loops. 3 studies (1.7 %) found that traceability is a prerequisite for *closing* resource loops, in terms of waste-to-energy strategy implementation (Mastos et al., 2021), wasted packaging material management and reduction purposes (Rane and Thakker, 2020), green product quality tracing, recyclability, and control of carbon footprints (Prajapati et al., 2022). 2 studies (1.15 %), namely Prajapati et al. (2022) and Varriale et al. (2020), add that traceability and transparency are required for *slowing* resource loops, e.g. given the enhanced tracking of food waste and its containers which is necessary for a safety food recycling after consumption. Packaging can be reused and traced; for example, Blockchain traceability can extend the packaging material life through more efficient management. Finally, 13 studies (7.47 %) explain how important traceability is for *narrowing* resource loops. This is, in fact, considered a key driver for optimal resource efficiency (Paliwal et al., 2020), reduced utilization of resources as occurred in the manufacturing of organic cotton for textile and clothing SC and other manufacturing industries (Agrawal et al., 2021; Han and Rani, 2022), waste reduction via tracing product's quality (Kouhizadeh and Sarkis, 2018; Kshetri, 2021; Rane and Thakker, 2020; Varriale et al., 2020), reduction of rework and recall due to accurate product tracking in the automotive (Ghadge et al., 2022) and agrifood SC (Anastasiadis et al., 2022), carbon footprint and emission reduction in food SCs (Yachai et al., 2021) and other manufacturing contexts (Khanfar et al., 2021; Manupati et al., 2020). Transparency and traceability empower customers to identify whether the products produced by manufacturers are environmentally friendly or not, which in turn enforce manufacturers to practice environmentally friendly manners and reduce emissions. (Khanfar et al., 2021) (Table 3).

4.2. Which DT enables the design of a specific CSC archetype?

Table 4 reports the results of content analyses describing the DTs enabling the design of specific CSC archetypes by *closing, slowing, intensifying, narrowing*, and *dematerializing* resource streams. These include Big Data Analytics, Artificial Intelligence, Additive Manufacturing, Internet of Things, Blockchain and Cloud Computing technologies. In the following, the results of content analyses are presented.

4.2.1. Big data analytics (BDA)

BDA allow decision makers analysing large volume of data throughout the value chain concerning e.g., manufactured products, market conditions, consumers' behaviours, production activities etc., so unlocking new patterns and knowledge about them (Wang et al., 2020b). BDA-oriented SC is also proven to positively influence the effect of CE HR management on firms' performance, as employees can be oriented towards data-driven decisions and optimized CSC solutions by applying statistical techniques to the large amounts of data collected (Del Giudice et al., 2020). This is beneficial for *narrowing* resource loops within the same SC stage or between different ones, as stated by 23 papers (13.22 %). For example, manufacturing companies exploit BDA to rethink and redesign existing products and processes toward optimal resource allocation (Wang et al., 2016; Bag et al., 2020; Bag et al., 2021), resource efficiency e.g., with minimum need of virgin materials and primary energy (Dubey et al., 2016; Papadopoulos et al., 2017; Raut et al., 2019; Singh and El-Kassar, 2019; Song et al., 2019), and reduction in carbon footprints and polluting substances (Badiezadeh et al., 2018; Belhadi et al., 2022; Chalmeta and Barqueros-Muñoz, 2021; Chang et al., 2011; Chiappetta Jabbour et al., 2020; Del Giudice et al., 2020; Edwin Cheng et al., 2022; Feng et al., 2022; Kunkel et al., 2022; Mageto, 2021; Mangina et al., 2020; Singh and El-Kassar, 2019; Song et al., 2019; Zhang et al., 2022; Zheng et al., 2021), but also to prevent maintenance through prediction-based failure analyses on material, parts, and components (Kumar et al., 2018; Zhang et al., 2019), and to identify eco-friendly materials for new product development, through cooperation with suppliers, and/or for eco-packaging solutions, through cooperation with suppliers and distributors (Dubey et al., 2016). 12 articles (6.90 %) argue that the adoption of BDA is proven to be beneficial also for *slowing* resource loops given the enhanced planning of disassembly activities for remanufacturing (Marconi et al., 2019; Rosa et al., 2020), the support for preventive maintenance on material, parts, and components through prediction-based failure analyses (Kumar et al., 2018; Zhang et al., 2019;), increased accuracy of decisions regarding product reuse (Bag et al., 2021; Belhadi et al., 2022; Bressanelli et al., 2021; Edwin Cheng et al., 2022; Feng et al., 2022; Raut et al., 2019; Xiang and Xu, 2020; Zheng et al., 2021). On the contrary, 11 studies (6.32%)

Table 3
The thematic classification of studies analysing the SC Capabilities required for the design of specific CSC archetypes.

SC capabilities	Closing	Slowing	Narrowing	Intensifying	Dematerializing
Intra-sectorial collaboration	20 (11.49%)	13 (7.47%)	28 (16.09%)	10 (5.75%)	
Inter-sectorial collaboration	6 (3.45%)	6 (3.45%)	4 (2.30%)	1 (0.58%)	1 (0.58%)
Flexibility	6 (3.45%)	7 (4.02%)	8 (4.60%)	5 (2.87%)	
Visibility	18 (10.35%)	9 (5.17%)	28 (16.09%)	6 (3.45%)	2 (1.15%)
Traceability	3 (1.72%)	2 (1.15%)	13 (7.47%)		
Tot. # of studies	**31 (17.82%)**	**20 (11.49%)**	**42 (24.14%)**	**13 (7.47%)**	3 **(1.72%)**

examined the use of BDA for *closing* resource loops given the enabled design for product recycling and remanufacturing (Ge and Jackson, 2014; Lin, 2018), increased efficiency of waste collection and recycling operations (Bag et al., 2021; Belhadi et al., 2022; Dubey et al., 2016; Edwin Cheng et al., 2022; Feng et al., 2022; Kunkel et al., 2022; Rosa et al., 2020; Xiang and Xu, 2020), and increased accuracy of decisions regarding the use of by-products and secondary raw materials (Raut et al., 2019). In accordance with 3 papers (1.72 %), BDA could also be exploited for *dematerializing* resource loops (Belhadi et al., 2022; Montag, 2023) e.g., supporting the servitization process of firms aiming to increase their long-term competitive advantage through the ideation and implementation of product-services in collaboration (Opresnik and Taisch, 2015).

4.2.2. Artificial intelligence (AI)

By predicting waste materials availability and the demand for goods in the marketplace, AI allows “the business to optimize the value chain by eliminating needless storage and possible shortages, thus lowering costs and boosting revenues” (Khan et al., 2022b). AI enables waste collection and reuse/remanufacturing/recycling operations while *closing* (Bag et al., 2021; Chidepatil et al., 2020; Khan et al., 2022b; Wilson et al., 2022) and *slowing* resource loops (Bag et al., 2021; Zheng et al., 2021; Wilson et al., 2022), according to 4 (2.30 %) and 3 (1.72 %) studies, respectively. More studied in literature is the use of AI and its various sub-systems, e.g. Machine Learning (ML), for *narrowing* resource loops (Bag et al., 2021; Ding, 2018; Feng et al., 2022; Hofmann and Rutschmann, 2018; Kunkel et al., 2022; Lorena et al., 2011; Morellos et al., 2016; McNider et al., 2015; Romagnoli et al., 2023; Sharma et al., 2022; Traore et al., 2016; Zhang et al., 2022), in fact examined by 12 articles (6.90 %). ML algorithms are applied in the pre-production stage for forecasting crop yield, soil properties, and irrigation requirements. For example, it helps in improving the soil management practices according to the land potential (Ding, 2018; Morellos et al., 2016). Similarly, ML is used for weather forecasting that guide the optimal use of water for crop irrigation scheduling and planning (McNider et al., 2015; Traore et al., 2016). ML is also a useful technology for managing livestock during the production phase. Finally, the use of ML is applicable for demand estimation that help to avoid overstocking, overproduction, and overutilization of resources (Hofmann and Rutschmann, 2018). For production planning ML algorithms help inefficient production planning through the reduction of setup time and better demand sensing (Lorena et al., 2011). In particular, the sorting of food, the maintenance of the highest quality of compliance in terms of health and safety allows a very considerable reduction of food waste and losses. Even in the field of agriculture, systematic irrigation using AI is another practical example of its use to improve the factors related to the use of pesticides and fertilizers. Systematic irrigation is about optimizing the irrigation process and thus minimizing the use of resources. From the results obtained, only 1 article (0.58 %), i.e., Mahroof et al. (2021), describes in a structured way the contribution of AI for *dematerializing* resource loops, incentivizing service-oriented business models, such as Drone-as-a-Service which leverages AI drones that facilitate prediction of crop output by minimizing disturbances in agricultural SC.

4.2.3. Additive manufacturing (AM)

AM technologies provide firms with innovative and flexible solutions for the design and manufacturing of circular products characterized by optimal resource efficiency and minimum environmental impact. They enable the companies to meet customer demands for high-quality items on schedule, with less waste and emissions (Abideen et al., 2021; Belhadi et al., 2022; Despeisse et al., 2017; Dev et al., 2020; Feng et al., 2022; Holmstrom and Gutowski, 2017; Hazen et al., 2020; Huang et al., 2013; Jabbour et al., 2018; Rinaldi et al., 2021; Shahpasand et al., 2023; Sun and Zhao, 2017; Tang et al., 2016; Thomas and Mishra, 2022; Tziantopoulos et al., 2019; Woodson, 2015). AM is proven to be beneficial for *narrowing* resource loops, as established by 23 papers (13.22 %) among those examined. Reduction in material use and scrap production are inherent to the technology itself given that AM-based manufacturing processes work through material addiction, rather than removal. Furthermore, compared to conventional manufacturing processes, 3D printing technologies allow product eco-design e.g., with increased use of bio-based materials (Van der Voet et al., 2019), lightweight design (Huang et al., 2013), and the design for repair and remanufacturing (Kellens et al., 2017), thus lowering the amount of required input resources (material and energy) and semi-finished manufactured products (Gebler et al., 2014). In such a case, suppliers and distributors significantly reduce the carbon emissions due to reduced logistic activities of raw materials, spare parts, and semi-finished manufactured products (Li et al., 2016). Low carbon emissions are achieved also as a result of reduced number of SC tiers as some operations e.g., assembly or certain material supply, can be eliminated (Kellens et al., 2017; Li et al., 2016; Santander et al., 2020). On-demand production, enabled by AM technologies (Holmstrom and Gutowski, 2017), reduce manufacturing, inventory overstocking e.g., of spare parts (Afshari et al., 2020; Gebler et al., 2014; Kellens et al., 2017), and logistics activities as products can be manufactured close to the customers (Li et al., 2017). This is also true for packaging materials e.g., food containers, that can be 3D printed by retailers in the stores using recycled materials, thus reducing the need for virgin materials and inventory management.

While 17 studies (9.77 %) state that AM is beneficial for *closing* resource loops by fostering the recycling of waste as secondary raw materials (urban waste, scraps, foodstuffs, unfused material powder, iron materials, discarded plastics, etc.) (Belhadi et al., 2022; Despeisse et al., 2017; Dotchev and Yussof, 2009; Mattos Nascimento et al., 2019; Millard et al., 2018; Peng et al., 2018; Petrovic et al., 2011; Rosa et al., 2020; Santander et al., 2020; Shahpasand et al., 2023; Sun and Zhao, 2017; Sun et al., 2020) or for eco-packaging upgrading recycling processes (Clemon and Zohdi, 2018; Mandil et al., 2016; Sauerwein and Doubrovski, 2018; Woern et al., 2018; Zhong and Pearce, 2018) as many as 16 (9.20 %) argue the same but for *slowing* resource loops since its role is proven for the increased use of remanufactured products/components (Belhadi et al., 2022; Despeisse et al., 2017; González-Sánchez et al., 2020; Kellens et al., 2017; Kerin and Pham, 2019; Lahrour and Brissaud, 2018; Leino et al., 2016; Romagnoli et al., 2023; Rosa et al., 2020; Sun and Zhao, 2017; Zheng et al., 2021), and the reuse of materials for production and packaging purposes (Afshari et al., 2019; Gebler et al., 2014; Kellens et al., 2017; Li et al., 2016; Petrovic et al., 2011; Yang et al., 2018). This implies both decreased rate of waste production and disposal, and the reduction of the carbon emissions since pre-treatment

Table 4
The DTs enabling the design of a specific CSC archetype.

DT	CSC archetype				
	Closing	Slowing	Narrowing	Intensifying	Dematerializing
BDA	(Bag et al., 2021; Belhadi et al., 2022; Dubey et al., 2016; Edwin Cheng et al., 2022; Feng et al., 2022; Ge and Jackson, 2014; Kunkel et al., 2022; Lin, 2018; Raut et al., 2019; Rosa et al., 2020; Xiang and Xu, 2020)	(Bag et al., 2021; Belhadi et al., 2022; Bressanelli et al., 2021; Edwin Cheng et al., 2022; Feng et al., 2022; Kumar et al., 2018; Marconi et al., 2019; Raut et al., 2019; Rosa et al., 2020; Xiang and Xu, 2020; Zhang et al., 2019; Zheng et al., 2021)	(Bag et al., 2021; Badiezadeh et al., 2018; Bag et al., 2020; Belhadi et al., 2022; Chalmeta and Barqueros-Muñoz, 2021; Chang et al., 2011; Chiappetta Jabbour et al., 2020; Del Giudice et al., 2020; Dubey et al., 2016; Edwin Cheng et al., 2022; Feng et al., 2022; Kumar et al., 2018; Kunkel et al., 2022; Mageto, 2021; Mangina et al., 2020; Papadopoulos et al., 2017; Raut et al., 2019; Singh and El-Kassar, 2019; Song et al., 2019; Wang et al., 2016; Zhang et al., 2019; Zhang et al., 2022; Zheng et al., 2021)		(Belhadi et al., 2022; Opresnik and Taisch, 2015; Montag, 2023)
AI	(Bag et al., 2021; Chidepatil et al., 2020; Khan et al., 2022b; Wilson et al., 2022)	(Bag et al., 2021; Zheng et al., 2021; Wilson et al., 2022)	(Bag et al., 2021; Ding, 2018; Feng et al., 2022; Hofmann and Rutschmann, 2018; Kunkel et al., 2022; Lorena et al., 2011; Morellos et al., 2016; McNider et al., 2015; Romagnoli et al., 2023; Sharma et al., 2022; Traore et al., 2016; Zhang et al., 2022)		(Mahroof et al., 2021)
AM	(Belhadi et al., 2022; Clemon and Zohdi, 2018; Despeisse et al., 2017; Dotchev and Yussof, 2009; Mandil et al., 2016; Mattos Nascimento et al., 2019; Millard et al., 2018; Peng et al., 2018; Petrovic et al., 2011; Rosa et al., 2020; Santander et al., 2020; Sauerwein and Doubrovski, 2018; Shahpasand et al., 2023; Sun and Zhao, 2017; Sun et al., 2020; Woern et al., 2018; Zhong and Pearce, 2018)	(Afshari et al., 2019; Belhadi et al., 2022; Despeisse et al., 2017; Gebler et al., 2014; González-Sánchez et al., 2020; Kellens et al., 2017; Kerin and Pham, 2019; Lahrour and Brissaud, 2018; Leino et al., 2016; Li et al., 2016; Petrovic et al., 2011; Romagnoli et al., 2023; Rosa et al., 2020; Sun and Zhao, 2017; Yang et al., 2018; Zheng et al., 2021)	(Abideen et al., 2021; Afshari et al., 2020; Belhadi et al., 2022; Despeisse et al., 2017; Dev et al., 2020; Feng et al., 2022; Gebler et al., 2014; Holmstrom and Gutowski, 2017; Hazen et al., 2020; Huang et al., 2013; Kellens et al., 2017; Li et al., 2016; Li et al., 2017; Jabbour et al., 2018; Rinaldi et al., 2021; Santander et al., 2020; Shahpasand et al., 2023; Sun and Zhao, 2017; Tang et al., 2016; Thomas and Mishra, 2022; Tziantopoulos et al., 2019; Van der Voet et al., 2019; Woodson, 2015)	(Mortara and Parisot, 2016; Rayna et al., 2015; Zanetti et al., 2016)	(Belhadi et al., 2022; Despeisse et al., 2017; Dev et al., 2020; Jabbour et al., 2018; Mortara and Parisot, 2016; Rayna et al., 2015; Zanetti et al., 2016)
IoT	(Belhadi et al., 2022; Bressanelli et al., 2021; Chaudhari et al., 2022; Delpla et al., 2022; Dev et al., 2020; De Vass et al., 2021; Garrido-Hidalgo et al., 2019; Garrido-Hidalgo et al., 2020; Ghadge et al., 2022; Guo and Zhong, 2023; Jabbour et al., 2018; Mastos et al., 2020; Mosallanezhad et al., 2023; Pieroni et al., 2020; Preut et al., 2021; Rajput and Singh, 2019; Rane and Thakker, 2020)	(Belhadi et al., 2022; Bressanelli et al., 2021; Chaudhari et al., 2022; Delpla et al., 2022; Dev et al., 2020; Garcia-Muiña et al., 2018; Garrido-Hidalgo et al., 2019; Garrido-Hidalgo et al., 2020; Ghadge et al., 2022; Guo and Zhong, 2023; Jabbour et al., 2018; Kerin and Pham, 2019; Ma and Mo, 2023; Preut et al., 2021; Rane and Thakker, 2020; Zheng et al., 2021)	(Bechtsis et al., 2018; Belhadi et al., 2022; Bibi et al., 2017; Dev et al., 2020; De Vass et al., 2021; Feng et al., 2022; Guo and Zhong, 2023; Jabbour et al., 2018; Khan et al., 2022b; Kunkel et al., 2022; Lavelli, 2021; Ma and Mo, 2023; Khan et al., 2023;Pal and Kant, 2018; Preut et al., 2021; Rajput and Singh, 2019; Rane and Thakker, 2020; Romagnoli et al., 2023; Shrouf et al., 2014; Zheng et al., 2021)	(Dev et al., 2020; Jabbour et al., 2018; Preut et al., 2021)	(Belhadi et al., 2022; Bressanelli et al., 2021; Dev et al., 2020; Jabbour et al., 2018; Montag, 2023; Preut et al., 2021; Rymaszewska et al., 2017)
BC	(Böckel et al., 2021; Centobelli et al., 2022; Chidepatil et al., 2020; De Giovanni, 2022; Erses Yay, 2015; Esmaeilian et al., 2020; Ghadge et al., 2022; Gong et al., 2022a; Gong et al., 2022b; Hrouga et al., 2022; Kayikci et al., 2022; Khanfar et al., 2021; Khoo, 2019; Kouhizadeh and Sarkis, 2018; Liu et al., 2021; Ma et al., 2022; Mastos et al., 2021; Mukherjee et al., 2021; Paul et al., 2022; Pieroni et al., 2020; Rane and Thakker, 2020; Rejeb et al., 2023; Saberi et al., 2019; Varriale et al., 2020; Wang et al., 2020a; Zhang, 2019; Zhang et al., 2019; Zhang et al., 2020)	(Centobelli et al., 2022; De Giovanni, 2022; Ghadge et al., 2022; Kayikci et al., 2022; Kouhizadeh and Sarkis, 2018; Mastos et al., 2021; Mukherjee et al., 2021; Paul et al., 2022; Rane and Thakker, 2020; Rejeb et al., 2023; Varriale et al., 2020; Wang et al., 2020a; Zheng et al., 2021)	(Cetindamar et al., 2022; Centobelli et al., 2022; Cole et al., 2019; Di Vaio and Varriale, 2020; Esmaeilian et al., 2020; Feng et al., 2022; Kayikci et al., 2022; Khan et al., 2022a; Khanfar et al., 2021; Kouhizadeh and Sarkis, 2018; Kouhizadeh et al., 2019; Kouhizadeh et al., 2021; Kunkel et al., 2022; Mangla et al., 2022; Manupati et al., 2020; Mastos et al., 2021; Mubarik et al., 2021; Mukherjee et al., 2021; Parmentola et al., 2022; Paul et al., 2022; Rane and Thakker, 2020; Rejeb and Rejeb, 2020; Rejeb et al., 2023; Saberi et al., 2019; Sislian and Jaegler, 2022; Tan et al., 2020; Umar et al., 2022; Varriale et al., 2020; Wang et al.,	(Kayikci et al., 2022; Kouhizadeh and Sarkis, 2018; Mastos et al., 2021; Pazaitis et al., 2017; Rejeb et al., 2023; Wang et al., 2020a; Zhang, 2019)	(Kayikci et al., 2022; Mastos et al., 2021; Pazaitis et al., 2017; Rejeb et al., 2023; Wang et al., 2020a)

(*continued on next page*)

Table 4 (*continued*)

			2020a; Yousefi and Tosarkani, 2022; Zhang, 2019; Zhang et al., 2019; Zhang et al., 2020)		
CC	(Dev et al., 2020; Jabbour et al., 2018)	(Bressanelli et al., 2021; Dev et al., 2020; Jabbour et al., 2018; Zheng et al., 2021)		(Dev et al., 2020; Jabbour et al., 2018)	(Dev et al., 2020; Jabbour et al., 2018; Montag, 2023; Zheng et al., 2021)

of raw materials is no more necessary. Promoting collaborative production models through the development of systems for shared manufacturing services e.g., online fab-spaces and 3D-printing hubs (Belhadi et al., 2022; Despeisse et al., 2017; Dev et al., 2020; Jabbour et al., 2018; Mortara and Parisot, 2016; Rayna et al., 2015; Zanetti et al., 2016), AM is also beneficial for *intensifying* and *dematerializing* resource loops, as indicated by 3 (1.72 %) and 7 (4.02 %) articles, respectively.

4.2.4. *Internet of Things (IoT)*

IoT technologies ensure “physical objects” being “digitally connected to sense, monitor and interact within a company and between the company and its supply chain” (Ben-Daya et al., 2019). This allows tracking and tracing materials throughout the entire product cycle (Garrido-Hidalgo et al., 2019; Mastos et al., 2020) as in the case of waste electric and electronic components (Garrido-Hidalgo et al., 2019; Garrido-Hidalgo et al., 2020), enabling the collection, inspection, disassembly, remanufacturing, refurbishing, shipment, and recycling of resources (Belhadi et al., 2022; Bressanelli et al., 2021; Chaudhari et al., 2022; Delpla et al., 2022; Dev et al., 2020; De Vass et al., 2021; Garcia-Muiña et al., 2018; Garrido-Hidalgo et al., 2019; Garrido-Hidalgo et al., 2020; Ghadge et al., 2022; Guo and Zhong, 2023; Jabbour et al., 2018; Kerin and Pham, 2019; Ma and Mo, 2023; Mastos et al., 2020; Mosallanezhad et al., 2023; Pieroni et al., 2020; Preut et al., 2021; Rajput and Singh, 2019; Rane and Thakker, 2020; Zheng et al., 2021), e.g., EVBs and related components, considering their repurposing as well through second-hand markets (Garrido-Hidalgo et al., 2020). IoT sensors, such as thermocouples, RTDs and infrared cameras that detect temperature, as well as accelerometers and microphones that detect vibration and noise, are used to continuously monitor condition-based maintenance for critical machine tools and processes that handle hazardous materials (Chaudhari et al., 2022). According to Delpla et al. (2022), IoT can collect precise data on items in terms of life cycle, disassembly, or location in relation to collection sites using devices, e.g., embedded sensors and linear programming models. When IoT is used, for instance, to precisely pick recoverable EOL products by anticipating their degradation stage and creating digital twins, it can also support a significant increase in profitability. All this is beneficial for *closing* and *slowing* resource loops, as established by 17 (9.77 %) and 16 (9.20 %) papers, respectively. Instead, 20 studies (11.49 %) observe that the implementation of IoT is beneficial for *narrowing* resource loops (Bechtsis et al., 2018; Belhadi et al., 2022; Bibi et al., 2017; Dev et al., 2020; De Vass et al., 2021; Feng et al., 2022; Guo and Zhong, 2023; Jabbour et al., 2018; Khan et al., 2022b; Kunkel et al., 2022; Lavelli, 2021; Ma and Mo, 2023; Khan et al., 2023; Pal and Kant, 2018; Preut et al., 2021; Rajput and Singh, 2019; Rane and Thakker, 2020; Romagnoli et al., 2023; Shrouf et al., 2014; Zheng et al., 2021). Pal and Kant (2018) discussed the opportunities that exists with sensor-based infrastructure to monitor food SC which can reduce the food waste. Bibi et al. (2017) reviewed RFID sensors, which can be used in food SC to track food condition so that spoiled foods can be avoided. Khan et al. (2022b) highlight that IoT technologies support the use of machine data in product development, directing data that can be used to improve machine fuel consumption to reduce resource flows while increasing products’ desirability and accessibility for purchase by the consumer. The most innovative companies could exploit IoT-powered tools and strategies to set up effective sharing economy models for *intensifying* resource loops (Dev et al., 2020; Jabbour et al., 2018; Preut et al., 2021), based on 3 articles (1.72%), or start digitalization and servitization projects in order to increase profitability and customer satisfaction by *dematerializing* resource loops (Belhadi et al., 2022; Bressanelli et al., 2021; Dev et al., 2020; Jabbour et al., 2018; Montag, 2023; Preut et al., 2021; Rymaszewska et al., 2017), as argued by 7 papers (4.02 %).

4.2.5. *Blockchain (BC)*

Continuous tracking of resources, products and materials inventory, by-products, secondary raw materials and waste is possible through a full integration of BC technologies with SC processes throughout all the product value chain (Böckel et al., 2021; Centobelli et al., 2022; Chidepatil et al., 2020; De Giovanni, 2022; Erses Yay, 2015; Esmaeilian et al., 2020; Ghadge et al., 2022; Gong et al., 2022a; Gong et al., 2022b; Hrouga et al., 2022; Kayikci et al., 2022; Khanfar et al., 2021; Khoo, 2019; Kouhizadeh and Sarkis, 2018; Liu et al., 2021; Ma et al., 2022; Mastos et al., 2021; Mukherjee et al., 2021; Paul et al., 2022; Pieroni et al., 2020; Rane and Thakker, 2020; Rejeb et al., 2023; Saberi et al., 2019; Varriale et al., 2020; Wang et al., 2020a; Zhang, 2019; Zhang et al., 2019; Zhang et al., 2020). BC is proven to be beneficial for *closing* resource loops, as emerges from 28 articles (16.09 %). BC can also help with restructuring and recycling from producers and consumers by tracking material and resource flows through various SCs and consumption stages (Böckel et al., 2021). For instance, it can address information issues related to the availability and suitability of raw materials in recycled plastic and enhance the processes of sorting and recycling of plastic waste. BC-based information regarding e.g., product running status, component lifetime, allow ease identification of which components needs to be recycled (Zhang et al., 2019) or can be reused/remanufactured by *slowing* resource loops (Centobelli et al., 2022; De Giovanni, 2022; Ghadge et al., 2022; Kayikci et al., 2022; Kouhizadeh and Sarkis, 2018; Mastos et al., 2021; Mukherjee et al., 2021; Paul et al., 2022; Rane and Thakker, 2020; Rejeb et al., 2023; Varriale et al., 2020; Wang et al., 2020a; Zheng et al., 2021), as indicated by 13 studies (7.47 %), and suggest to decision-makers how to develop strategic planning for waste management (Erses Yay, 2015; Khoo, 2019). Also *narrowing* resource loops is favoured by the implementation of BC, as stated by 33 papers (18.97 %) which make this as the most discussed DT-CSC archetype relationship of all. By better managing and tracking waste flows at all stages with less intermediation (horizontal integration) and ensuring responsibility attribution throughout the waste lifecycle (vertical integration), BC could then push towards more narrow resource loops (Cetindamar et al., 2022; Centobelli et al., 2022; Cole et al., 2019; Di Vaio and Varriale, 2020; Esmaeilian et al., 2020; Feng et al., 2022; Kayikci et al., 2022; Khan et al., 2022a; Khanfar et al., 2021; Kouhizadeh and Sarkis, 2018; Kouhizadeh et al., 2021; Kunkel et al., 2022; Mangla et al., 2022; Manupati et al., 2020; Mastos et al., 2021; Mubarik et al., 2021; Mukherjee et al., 2021; Parmentola et al., 2022; Paul et al., 2022; Rane and Thakker, 2020; Rejeb and Rejeb, 2020; Rejeb et al., 2023; Sislian and Jaegler, 2022; Tan et al., 2020; Umar et al., 2022; Varriale et al., 2020; Yousefi and Tosarkani, 2022; Zhang, 2019). Data on energy consumption throughout the entire product life-cycle can suggest to product designers modifying design schemes and selecting suitable materials and components to achieve low energy consumption (Zhang et al., 2020), inform consumers for using the product properly to reduce unnecessary energy consumption, and inform enterprises valuable knowledge to reconsider product use and to redesign products that will generate less or no waste at the end of their life (Zhang et al., 2019). Kouhizadeh et al. (2019) underline that BC help firms to verify the reliability of green products and identify products made up of non-renewable resources, in order to eliminate them and invest in alternative green resources. According to Saberi et al. (2019), BC technology allows firms easily tracking the carbon footprint of their products via the transactions of carbon assets (digital currency) under a pre-programmed smart contract. Focusing on the fast fashion industry, Wang et al. (2020a) highlight how BC could offer practical solutions for any phase of the products history, enabling network decentralization and collaboration in the pre-production stage, providing security and speed, and reducing the amount of inventory in the production stage and improving traceability, selection of suppliers and management of sustainability issues in the post-production phase. BC also provides innovative ownership and financing models for goods and services used e.g., in the construction industry, creating an environment of trust among SC partners who feel more involved and motivated to be transparent and to share their resources even for non-profit goals. All of this proves that BC can be fundamental for *intensifying* (Kayikci et al., 2022; Kouhizadeh and Sarkis, 2018; Mastos et al., 2021; Pazaitis et al., 2017; Rejeb et al., 2023; Wang et al., 2020a; Zhang, 2019) and *dematerializing* (Kayikci et al., 2022; Mastos et al., 2021; Pazaitis et al., 2017; Rejeb et al., 2023; Wang et al., 2020a) resource loops, in accordance with 7 (4.02 %) and 5 (2.87 %) papers.

4.2.6. *Cloud computing (CC)*

CC technologies have disrupted manufacturing processes, by providing a networked and distributed approach for collaborative manufacturing businesses. Based on 2 articles (1.15 %), this is proven to be beneficial for *closing* resource loops. According to Dev et al., 2020 and Jabbour et al., 2018, CC platforms enable recycling practices; for example, firms in industrial symbiosis networks can share information regarding their by-product flows through them, thus favouring their use as secondary materials within the same value chain or a different one. These platforms allow suppliers and producers to better manage the information on e.g., stock level, thereby reducing the risk of overstocking. 4 studies (2.30 %) state that CC-based systems help to enable computing product returns by providing a common platform for the entire SC to collect and transfer production and remanufacturing signals, while *slowing* resource loops (Bressanelli et al., 2021; Dev et al., 2020; Jabbour et al., 2018; Zheng et al., 2021). From the literature, it is evident that the CC is not the ideal DT for *narrowing* resource loops, since for example it cannot intervene directly in the production and logistics processes by reducing the amount of waste or polluting agents; on the other hand, according to 2 (1.15 %) and 4 (2.30 %) studies, respectively, it seems to be functional for *intensifying* and *dematerializing* resource loops as it allows for the generation of digital environments that can interconnect partners and end-customers for the sharing of resources and the provision of strategic services (Dev et al., 2020; Jabbour et al., 2018; Montag, 2023; Zheng et al., 2021) (Table 5).

5. Discussion

Which SC capability is required for the design of a specific CSC archetype? Which DT enables the design of a specific CSC archetype? In this study, we conducted a systematic literature review to summarize existing key findings addressing these two important questions. The results of our content analyses show a non-homogeneous distribution of studies on the CSC archetypes, since the most investigated one is *narrowing* (66.6%), followed by *closing* (47.1 %), *slowing* (33.9 %), *intensifying* (13.2 %) and *dematerializing* (12.1 %). Despite a distinguishing feature of CSCs is to maintain resources at their highest utility value for as long as feasible so as to maximize their availability for consumption (Vegter et al., 2020; Montag, 2022), literature on *intensifying* and *dematerializing* resource streams is still not yet mature as demonstrated by the low number of studies investigating the capabilities and DTs required for their design. Instead, *narrowing, closing,* and *slowing* resource streams still represent the most-reported approaches to re-design traditional SCs into CSCs, probably because recycling, remanufacturing, repair, and reduce are still perceived as the core strategies for CE implementation (EMF, 2013; Gusmerotti et al., 2019; Mhatre et al., 2021; Potting et al., 2017). As our results show, specific capabilities are required for *closing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *slowing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *narrowing* (inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, traceability), *intensifying* (intra-sectorial collaboration, inter-sectorial collaboration, flexibility, visibility), and dematerializing (inter-sectorial collaboration, visibility) resource streams. Among these, intra-sectorial collaboration and visibility are the most-reported SC capabilities enabling the design of CSC archetypes. Further room for future research regards downstream intra-sectorial collaboration, intra-sectorial coopetition, and inter-sectorial collaboration. So far, a higher attention has been put on upstream intra-sectorial collaborations rather than downstream ones i.e., those involving the consumer. Future studies are suggested to understand whether and how manufacturer-to-customer collaborative models catalyze CSC design by *closing* and *slowing* resource streams. Horizontal coopetition established between firms operating in the same SC stage i.e., supplier-supplier or manufacturer-manufacturer etc., and serving the same market can be determinant for *slowing* resource loops as affecting the behaviors of the involved companies on reselling, recycling, refurbishing end-of-life components (Jalali et al., 2022). Inter-sectorial collaborations not only include the industrial symbiosis-kind relationships, as so far investigated, but also the relationships with external stakeholders as institutional, governmental, and societal actors (Aarikka-Stenroos et al., 2022; González-Sánchez et al., 2020; Govindan & Hasanagic, 2018). Future studies should conduct proper investigations to understand whether and how these partnerships enable the design of specific CSC archetypes. Also, there is the need to develop more studies on the adoption of servitization and *dematerializing* strategies on the SC level, with a particular emphasis on the capabilities and DTs SC firms are required to develop and/or strengthen and implement.

In a similar way, the combination of DTs is proven useful for *closing* (BDA, AI, AM, IoT, BC, CC), *slowing* (BDA, AI, AM, IoT, BC, CC), *narrowing* (BDA, AI, AM, IoT, BC), *intensifying* (AM, IoT, BC, CC), and *dematerializing* (BDA, AI, AM, IoT, BC, CC) resource streams. These results are in line with existing review studies summarizing the enabling role of DTs on the implementation of CE strategies and CBMs by SC companies (Ada et al., 2021; Furstenau et al., 2020; Hassoun et al., 2023; Rejeb and Appolloni, 2022; Taddei et al., 2022; Yu et al., 2022). DTs play as strategic tools to improve the level of flexibility, traceability, visibility, information-sharing along the entire SC, which in turn are

Table 5
The thematic classification of studies analyzing the DTs required for the design of specific CSC archetypes.

	Closing	Slowing	Narrowing	Intensifying	Dematerializing
BDA	11 (6.32%)	12 (6.90%)	23 (13.22%)		3 (1.72%)
AI	4 (2.30%)	3 (1.72%)	12 (6.90%)		1 (0.58%)
AM	17 (9.77%)	16 (9.20%)	23 (13.22%)	3 (1.72%)	7 (4.02%)
IoT	17 (9.77%)	16 (9.20%)	20 (11.49%)	3 (1.72%)	7 (4.02%)
BC	28 (16.09%)	13 (7.47%)	33 (18.97%)	7 (4.02%)	5 (2.87%)
CC	2 (1.15%)	4 (2.30%)		2 (1.15%)	4 (2.30%)
Tot. # of studies	**69 (39.66%)**	**48 (27.59%)**	**94 (54.02%)**	**13 (7.47%)**	**19 (10.92%)**

necessary capabilities to re-think competing and independent value chains into circular ecosystems as CSCs. While flexibility, visibility, and traceability better support demand prediction and the management of the flow of goods, such as allowing automatic position tracking and analysis of natural resources with the IoT, optimizing waste-to-resource alignment in industrial symbioses networks by real-time collection by Big Data for enhanced resource management (Kristoffersen et al., 2020), information-sharing foster the development of collaborative relationships within the same value chain (along the horizontal and vertical dimension) and between different sectors (along the lateral dimension). Among DTs, BDA, BC, AM, and IoT represent the most-implemented DTs enabling the design of CSC archetypes. One particular thing that emerges is the fact that the role of AI for CSC archetypes is among the least explored together with CC, despite the increased interest and use of AI-powered systems e.g., OpenAI's ChatGPT, now on the way to going mainstream. Besides focusing more on AI and CC, future studies could further explore the use of DTs for *narrowing* and *dematerializing* resource loops which are archetypes not covered much by the current literature. Waste management and reverse logistics turn to be the predominant topics in the DTs-CE intersection at the expense of more disruptive solutions at the SC level which require innovative business models and infrastructures, such as sharing platforms and product-service systems (PSS). In 2021, the European Commission called for a Fifth Industrial Revolution (Industry 5.0), possibly centered on three interconnected core values: human-centricity, sustainability and resilience (Xu et al., 2021). Therefore, further investigations could also focus on the influence of the emergent Industry 5.0 technologies, e.g., human-machine interaction technologies, bio-inspired systems, Digital Twins, and simulations, on the resource loop redesign for CSCs.

6. Conclusions

In the recent years, the design of CSCs is becoming one among most-pressing concerns of both SC scholars and manager as affecting the sustainable development of current and future populations. CSCs in fact operate as *self-sustained* systems designed to operate in a "*restorative and regenerative*" way by recapturing residual value from by-products, extracting new value from end-of-life resources, extending product life for as long as feasible, and increasing resource efficiency (Farooque et al., 2019; Genovese et al., 2017; Lahane et al., 2020; Nasir et al., 2017). According to previous studies, this is successfully achieved through the collective adoption of CBMs by multiple stakeholders i.e., those internal and external to the original SC boundaries (Bocken et al., 2016; Mangla et al., 2018; Sehnem et al., 2019). CBMs transform the prevailing linear resource management along the SC by *closing, slowing, intensifying, narrowing*, and *dematerializing* resource streams (Bocken et al., 2016), thus leading to specific CSC archetypes. By drawing on this less adopted classification, we consider important to review the state-of-the-art concerning the capabilities and DTs enabling the design of a specific CSC archetype. Our results identify and explain the corresponding relationships, thus providing important contributions to scholars and managers.

First, this study enriches the literature on CSCs by providing a new design perspective i.e., that based on resource loop re-design. So far, resource loops have been referred to as key elements affecting the CSC network of stakeholders as they can involve industrial stakeholders belonging to the same value chain i.e., closed loops, or to different value chains and industry domains i.e., open loops. As we noted in this study, however, the transformations occurring on the level of resource loops i.e., by *closing, slowing, narrowing, intensifying,* and *dematerializing* resource streams, help to identify the CSC archetypes. Resource loops also represent one among the sources of augmented complexity characterizing CSCs. Through them, in fact, additional and dynamic interdependences spread within the stakeholders' network as the result of multiple and diverse end-of-life resource streams, additional information concerning end-of-life products, waste, and by-products, and new value recovery activities. To tackle with such dynamic complexity, as we noted here, SC companies need to develop specific capabilities and adopt specific DTs as effective enablers. Overall, this new perspective intends to complement what provided by existing literature reviews so far presenting the role of DTs on the implementation of CE strategies (Ada et al., 2021; Furstenau et al., 2020; Hassoun et al., 2023; Rejeb and Appolloni, 2022; Yu et al., 2022) and CBMs (Taddei et al., 2022). Second, this study contributes to the literature on CSCs by addressing the capabilities and DTs required for the design of specific CSC archetype. As explained, inter-sectorial collaboration, intra-sectorial collaboration, flexibility, visibility, and traceability are considered prerequisites for the design of specific CSC archetypes while DTs as BDA, AI, AM, IoT, CC, and BC, by enabling the above capabilities, mitigate the augmented complexity of CSCs. In so doing, we inherently respond to the call by Jabbour et al. (2018). Third, future scholars can exploit the results of this study and the suggested research directions to add novel contributions toward the development of specific CSC archetypes. In particular, we inform future scholars that literature is currently more focused on certain CSCs archetypes i.e., those deriving from narrowing, closing, and slowing resource loops, and less on those deriving from intensifying and dematerializing them.

This study also provides few practical implications. First, it suggests managers paying more attention on the resource loops since representing key elements for the transition from linear to circular SCs. The SC redesign into a specific CSC archetype, in fact, occurs by *closing, slowing, narrowing, intensifying*, and *dematerializing* resource streams. At this regard, real cases of CSCs are used to emphasize the existing differences and application contexts. Second, this study raises managers' knowledge on the capabilities playing as prerequisite for the design of specific CSC archetypes. Third, we provide managers with useful directions and guidelines about how to exploit at most DTs to enable the design of specific CSC archetypes. In so doing, they can counterfit some barriers affecting the design of CSCs e.g., the lack of coordination and collaboration, achieving transparency through stakeholders, the uncertain investment returns of DTs (Munaro and Tavares, 2023; Ozkan-Ozen et al., 2020).

CRediT authorship contribution statement

GFM: Circular Supply Chains (2.1.), Research Methodology (3), Which SC capability is required for the design of a certain CSC archetype? (4.1), Discussion (5). RN: Classifying the archetypes of CSCs (2.2.), Which DT enables the design of a specific CSC archetype? (4.2.). IG: Introduction (1), Conclusions (6).

Declaration of Competing Interest

All the authors declare they have no conflicts of interest.

Data availability

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

Acknowledgments

Project funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3 - Call for tender No. 341 of 15/03/2022 of Italian Ministry of University and Research funded by the European Union – NextGenerationEU. Award Number: PE00000004, Concession Decree No. 1551 of 11/10/2022 adopted by the Italian Ministry of University and Research, CUP D93C22000920001, MICS (Made in Italy - Circular and Sustainable).

Appendix A

Table A1
The final dataset of 174 records used for result reporting.

ID	Article title	Journal name	Pub. year	# of citat.
1	A customer-centric IoT-based novel closed-loop supply chain model for WEEE management	Advanced Engineering Informatics	2023	0
2	Application of Internet of Things (IoT) in Sustainable Supply Chain Management	Sustainability (Switzerland)	2023	3
3	Integrating internet of things in service parts operations for sustainability	International Journal of Engineering Business Management	2023	0
4	Investigating environmental and economic impacts of the 3D printing technology on supply chains: The case of tire production	Journal of Cleaner Production	2023	2
5	Roadmap to a Circular Economy by 2030: A Comparative Review of Circular Business Model Visions in Germany and Japan	Sustainability (Switzerland)	2023	0
6	The Impact of Digital Technologies and Sustainable Practices on Circular Supply Chain Management	Logistics	2023	3
7	The IoT-enabled sustainable reverse supply chain for COVID-19 Pandemic Wastes (CPW)	Engineering Applications of Artificial Intelligence	2023	11
8	The role of blockchain technology in the transition toward the circular economy: Findings from a systematic literature review	Resources, Conservation and Recycling Advances	2023	1
9	Using emerging technologies to improve the sustainability and resilience of supply chains in a fuzzy environment in the context of COVID-19	Annals of Operations Research	2023	12
10	A conceptual framework for blockchain-based sustainable supply chain and evaluating implementation barriers: A case of the tea supply chain	Business Strategy and the Environment	2022	27
11	A self-assessment tool for evaluating the integration of circular economy and industry 4.0 principles in closed-loop supply chains	International Journal of Production Economics	2022	25
12	A sustainable circular economic supply chain system with waste minimization using 3D printing and emissions reduction in plastic reforming industry	Journal of Cleaner Production	2022	17
13	Achieving triple sustainability in closed-loop supply chain: The optimal combination of online platform sales format and blockchain-enabled recycling	Computers and Industrial Engineering	2022	2
14	An analytical approach for evaluating the impact of blockchain technology on sustainable supply chain performance	International Journal of Production Economics	2022	53
15	Blockchain and IoT embedded sustainable virtual closed-loop supply chain in E-commerce towards the circular economy	Computers and Industrial Engineering	2022	15
16	Blockchain application in circular marine plastic debris management	Industrial Marketing Management	2022	18
17	Blockchain technologies as enablers of supply chain mapping for sustainable supply chains	Business Strategy and the Environment	2022	46
18	Blockchain technology for bridging trust, traceability and transparency in circular supply chain	Information and Management	2022	112
19	Blockchain-based recycling and its impact on recycling performance: A network theory perspective	Business Strategy and the Environment	2022	19
20	Circular manufacturing 4.0: towards internet of things embedded closed-loop supply chains	International Journal of Advanced Manufacturing Technology	2022	10
21	Companies' circular business models enabled by supply chain collaborations: An empirical-based framework, synthesis, and research agenda	Industrial Marketing Management	2022	7
22	Critical success factors for implementing blockchain-based circular supply chain	Business Strategy and the Environment	2022	21
23	Digital technology and circular economy practices: future of supply chains	Operations Management Research	2022	23
24	Evaluate the barriers of blockchain technology adoption in sustainable supply chain management in the manufacturing sector using a novel Pythagorean fuzzy-CRITIC-CoCoSo approach	Operations Management Research	2022	14
25	Green supply chain innovation: Emergence, adoption, and challenges	International Journal of Production Economics	2022	29
26	Industry 4.0 and green supply chain practices: an empirical study	International Journal of Productivity and Performance Management	2022	32
27	Industry 4.0 in sustainable supply chain collaboration: Insights from an interview study with international buying firms and Chinese suppliers in the electronics industry	Resources, Conservation and Recycling	2022	14
28	Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs)	Business Strategy and the Environment	2022	76
29	Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives	International Journal of Operations and Production Management	2022	19
30	Link between Industry 4.0 and green supply chain management: Evidence from the automotive industry	Computers and Industrial Engineering	2022	19
31	Linkage of blockchain to enterprise resource planning systems for improving sustainable performance	Business Strategy and the Environment	2022	12
32	Linkages between big data analytics, circular economy, sustainable supply chain flexibility, and sustainable performance in manufacturing firms	International Journal of Production Research	2022	57
33	Linking green supply chain management practices with competitiveness during covid 19: The role of big data analytics	Technology in Society	2022	17
34	Modeling Barriers in Circular Economy Using TOPSIS: Perspective of Environmental Sustainability & Blockchain-IoT Technology	International Journal of Mathematical, Engineering and Management Sciences	2022	1
35	Overcoming barriers to cross-sector collaboration in circular supply chain management: a multi-method approach	Transportation Research Part E: Logistics and Transportation Review	2022	33
36	RFID-integrated blockchain-driven circular supply chain management: A system architecture for B2B tea industry	Industrial Marketing Management	2022	21
37	Smart circular supply chains to achieving SDGs for post-pandemic preparedness	Journal of Enterprise Information Management	2022	10
38	The circular economy meets artificial intelligence (AI): understanding the opportunities of AI for reverse logistics	Management of Environmental Quality: An International Journal	2022	41
39	The potentials of combining Blockchain technology and Internet of Things for digital reverse supply chain: A case study	Journal of Cleaner Production	2022	38
40	The role of artificial intelligence in supply chain management: mapping the territory	International Journal of Production Research	2022	27
41	The role of traceability in end-to-end circular agri-food supply chains	Industrial Marketing Management	2022	15

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Table A1 (*continued*)

42	Understanding Big Data Analytics Capability and Sustainable Supply Chains	Information Systems Management	2022	19
43	Application of blockchain technology for sustainability development in agricultural supply chain: Justification framework	Operations Management Research	2021	62
44	Applications of blockchain technology in sustainable manufacturing and supply chain management: A systematic review	Sustainability (Switzerland)	2021	63
45	Big data analytics in sustainable supply chain management: A focus on manufacturing supply chains	Sustainability (Switzerland)	2021	39
46	Blockchain and sustainable supply chain management in developing countries	International Journal of Information Management	2021	81
47	Blockchain for the circular economy: analysis of the research-practice gap	Sustainable Production and Consumption	2021	73
48	Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	International Journal of Production Economics	2021	434
49	Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry	Computers and Industrial Engineering	2021	142
50	Carbon footprint adaptation on green supply chain and logistics of papaya in Yasothon Province using geographic information system	Journal of Cleaner Production	2021	10
51	Circular food supply chains - Impact on value addition and safety	Trends in Food Science and Technology	2021	47
52	Digital twins for the circular economy	Sustainability (Switzerland)	2021	14
53	Drone as a Service (DaaS) in promoting cleaner agricultural production and Circular Economy for ethical Sustainable Supply Chain development	Journal of Cleaner Production	2021	29
54	Enablers, levers and benefits of Circular Economy in the Electrical and Electronic Equipment supply chain: a literature review	Journal of Cleaner Production	2021	72
55	Identify and rank the challenges of implementing sustainable supply chain blockchain technology using the bayesian best worst method	Technological and Economic Development of Economy	2021	30
56	Impact of blockchain technology on green supply chain practices: evidence from emerging economy	Management of Environmental Quality: An International Journal	2021	26
57	Introducing an application of an industry 4.0 solution for circular supply chain management	Journal of Cleaner Production	2021	72
58	Iot in supply chain management: a narrative on retail sector sustainability	International Journal of Logistics Research and Applications	2021	56
59	Leveraging capabilities of technology into a circular supply chain to build circular business models: A state-of-the-art systematic review	Sustainability (Switzerland)	2021	11
60	Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities	Technological Forecasting and Social Change	2021	234
61	Stakeholders' involvement in green supply chain: a perspective of blockchain IoT-integrated architecture	Management of Environmental Quality: An International Journal	2021	28
62	Technology selection in green supply chains - the effects of additive and traditional manufacturing	Journal of Cleaner Production	2021	42
63	The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review	International Journal of Production Research	2021	236
64	The impact of big data analytics and artificial intelligence on green supply chain process integration and hospital environmental performance	Technological Forecasting and Social Change	2021	129
65	Using big data for sustainability in supply chain management	Sustainability (Switzerland)	2021	16
66	A blockchain-based approach for a multi-echelon sustainable supply chain	International Journal of Production Research	2020	155
67	A blockchain-based framework for green logistics in supply chains	Sustainability (Switzerland)	2020	62
68	A robust fuzzy stochastic programming for sustainable procurement and logistics under hybrid uncertainty using big data	Journal of Cleaner Production	2020	75
69	Achieving a sustainable shipbuilding supply chain under I4.0 perspective	Journal of Cleaner Production	2020	78
70	Assessing relations between circular economy and Industry 4.0: a systematic literature review	International Journal of Production Research	2020	289
71	Big data analytics as an operational excellence approach to enhance sustainable supply chain performance	Resources, Conservation and Recycling	2020	246
72	Blockchain and IoT convergence—a systematic survey on technologies, protocols and security	Applied Sciences (Switzerland)	2020	11
73	Blockchain and supply chain sustainability	Logforum	2020	45
74	Blockchain for the future of sustainable supply chain management in Industry 4.0	Resources, Conservation and Recycling	2020	291
75	Blockchain technology for sustainable supply chain management: A systematic literature review and a classification framework	Sustainability (Switzerland)	2020	91
76	Blockchain technology in supply chain management for sustainable performance: Evidence from the airport industry	International Journal of Information Management	2020	198
77	Blockchain-based life cycle assessment: An implementation framework and system architecture	Resources, Conservation and Recycling	2020	146
78	Blockchain-enabled circular supply chain management: A system architecture for fast fashion	Computers in Industry	2020	103
79	Closed loop supply chain network for local and distributed plastic recycling for 3D printing: a MILP-based optimization approach	Resources, Conservation and Recycling	2020	79
80	Data analytics for sustainable global supply chains	Journal of Cleaner Production	2020	13
81	Digitally-enabled sustainable supply chains in the 21st century: A review and a research agenda	Science of the Total Environment	2020	126
82	Dynamic game strategies of a two-stage remanufacturing closed-loop supply chain considering Big Data marketing, technological innovation and overconfidence	Computers and Industrial Engineering	2020	55
83	From trash to cash: How blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste?	Administrative Sciences	2020	77
84	Green procurement process model based on blockchain-IoT integrated architecture for a sustainable business	Management of Environmental Quality: An International Journal	2020	54
85	Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance	Resources, Conservation and Recycling	2020	218
86	Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy	International Journal of Production Research	2020	198
87	Industry 4.0 sustainable supply chains: An application of an IoT enabled scrap metal management solution	Journal of Cleaner Production	2020	109
88	Main dimensions in the building of the circular supply chain: A literature review	Sustainability (Switzerland)	2020	79
89	Supply chain management for circular economy: conceptual framework and research agenda	International Journal of Logistics Management	2020	63
90	Supply chain management in the era of circular economy: the moderating effect of big data	International Journal of Logistics Management	2020	121

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Table A1 (*continued*)

91	Sustainable manufacturing and industry 4.0: what we know and what we don't	Journal of Enterprise Information Management	2020	101
92	Sustainable supply chain flexibility and its relationship to circular economy-target performance	International Journal of Production Research	2020	50
93	The adoption of Internet of Things in a Circular Supply Chain framework for the recovery of WEEE: The case of Lithium-ion electric vehicle battery packs	Waste Management	2020	92
94	The role of eco-innovation drivers in promoting additive manufacturing in supply chains	International Journal of Production Economics	2020	41
95	The unknown potential of blockchain for sustainable supply chains	Sustainability (Switzerland)	2020	36
96	Virgin or recycled? Optimal pricing of 3D printing platform and material suppliers in a closed-loop competitive circular supply chain	Resources, Conservation and Recycling	2020	35
97	A review of emerging industry 4.0 technologies in remanufacturing	Journal of Cleaner Production	2019	193
98	An end-to-end Internet of Things solution for Reverse Supply Chain Management in Industry 4.0	Computers in Industry	2019	92
99	Application of blockchain technology in incentivizing efficient use of rural wastes: A case study on Yitong System	Energy Procedia	2019	31
100	Applying Data Mining Technique to Disassembly Sequence Planning: A Method to Assess Effective Disassembly Time of Industrial Products	International Journal of Production Research	2019	58
101	At the nexus of blockchain technology, the circular economy, and product deletion	Applied Sciences (Switzerland)	2019	114
102	Barriers to smart waste management for a circular economy in China	Journal of Cleaner Production	2019	202
103	Blockchain technology and its relationships to sustainable supply chain management	International Journal of Production Research	2019	1441
104	Blockchain technology: implications for operations and supply chain management	Supply Chain Management	2019	390
105	Collaboration beyond the supply network for green innovation: insight from 11 cases	Supply Chain Management	2019	61
106	Connecting circular economy and industry 4.0	International Journal of Information Management	2019	283
107	Decision support for collaboration planning in sustainable supply chains	Journal of Cleaner Production	2019	110
108	Environmental implications of future demand scenarios for metals: methodology and application to the case of seven major metals	Journal of Industrial Ecology	2019	91
109	Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal	Journal of Manufacturing Technology Management	2019	433
110	Improving sustainable supply chain capabilities using social media in a decision-making model	Journal of Cleaner Production	2019	36
111	Investigating the effects of learning and forgetting on the feasibility of adopting additive manufacturing in supply chains	Computers & Industrial Engineering	2019	21
112	LCA of plastic waste recovery into recycled materials, energy and fuels in Singapore	Resources, Conservation and Recycling	2019	139
113	Linking big data analytics and operational sustainability practices for sustainable business management	Journal of Cleaner Production	2019	195
114	Role of big data analytics in developing sustainable capabilities	Journal of Cleaner Production	2019	225
115	Supply chain reconfiguration opportunities arising from additive manufacturing technologies in the digital era	Production Planning and Control	2019	44
116	Technological challenges of green innovation and sustainable resource management with large scale data	Technological Forecasting and Social Change	2019	197
117	A big data driven sustainable manufacturing framework for condition-based maintenance prediction	Journal of Computational Science	2018	102
118	A collaborative cloud service platform for realizing sustainable make-to-order apparel supply chain	Sustainability (Switzerland)	2018	18
119	A Technical Assessment of Product/Component *Re*-manufacturability for Additive Remanufacturing	Procedia CIRP	2018	38
120	Assessing sustainability of supply chains by double frontier network DEA: A big data approach	Computers and Operations Research	2018	102
121	Big data analytics and demand forecasting in supply chains: a conceptual analysis	International Journal of Logistics Management	2018	83
122	Blockchain practices, potentials, and perspectives in greening supply chains	Sustainability (Switzerland)	2018	318
123	Circular Economy in the building sector: Three cases and a collaboration tool	Journal of Cleaner production	2018	234
124	Exploring sustainable supply chain management: a social network perspective	Supply Chain Management	2018	49
125	Fused Particle Fabrication 3-D Printing: Recycled Materials' Optimization and Mechanical Properties	Materials	2018	106
126	Hidden potentials in open-loop supply chains for remanufacturing	International Journal of Logistics Management	2018	25
127	How do Fab-spaces enable entrepreneurship? Case studies of 'Makers' - Entrepreneurs	Journal of Manufacturing Technology Management	2018	18
128	Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations	Annals of Operations Research	2018	584
129	Intelligent Autonomous Vehicles in digital supply chains: A framework for integrating innovations towards sustainable value networks	Journal of Cleaner Production	2018	90
130	IoT-Based Sensing and Communications Infrastructure for the Fresh Food Supply Chain	Computer	2018	65
131	Is the Maker Movement Contributing to Sustainability?	Sustainability (Switzerland)	2018	26
132	Local and Recyclable Materials for Additive Manufacturing: 3D Printing with Mussel Shells	Materials Today Communications	2018	37
133	On the tolerable limits of granulated recycled material additives to maintain structural integrity	Construction and Building Materials	2018	17
134	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains	Process Safety and Environmental Protection	2018	162
135	Recent progress in biomimetic additive manufacturing technology: from materials to functional structures	Advanced Materials	2018	280
136	Supply chain collaboration in industrial symbiosis networks	Journal of cleaner production	2018	168
137	Sustainability of additive manufacturing: An overview on its energy demand and environmental impact	Additive Manufacturing	2018	203
138	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	Social Sciences	2018	130
139	Tightening the loop on the circular economy: Coupled distributed recycling and manufacturing with recyclebot and RepRap 3-D printing	Resources, Conservation and Recycling	2018	130
140	User experience-based product design for smart production to empower industry 4.0 in the glass recycling circular economy	Computers & Industrial Engineering	2018	94
141	A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products	Trends in Food Science and Technology	2017	191

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Table A1 (*continued*)

142	Additive Manufacturing in Operations and Supply Chain Management: No Sustainability Benefit or Virtuous Knock-On Opportunities?	Journal of Industrial Ecology	2017	40
143	Additive manufacturing technology in spare parts supply chain: a comparative study	International Journal of Production Research	2017	133
144	Big-data analytics framework for incorporating smallholders in sustainable palm oil production	Production Planning and Control	2017	38
145	Blockchain and value systems in the sharing economy: The illustrative case of Backfeed	Technological Forecasting and Social Change	2017	250
146	Environmental Dimensions of Additive Manufacturing: Mapping Application Domains and Their Environmental Implications	Journal of Industrial Ecology	2017	165
147	Envisioning the era of 3D printing: a conceptual model for the fashion industry	Fashion and Textiles	2017	48
148	IoT powered servitization of manufacturing–an exploratory case study	International journal of production economics	2017	324
149	The role of Big Data in explaining disaster resilience in supply chains for sustainability	Journal of Cleaner Production	2017	398
150	Unlocking value for a circular economy through 3D printing: A research agenda	Technological Forecasting and Social Change	2017	277
151	A framework to reduce product environmental impact through design optimization for additive manufacturing	Journal of Cleaner Production	2016	144
152	A scientific workflow management system architecture and its scheduling based on cloud service platform for manufacturing big data analytics	International Journal of Advanced Manufacturing Technology	2016	71
153	Additive Manufacturing and PSS: a Solution Life-Cycle Perspective	IFAC-PapersOnLine	2016	16
154	Big data analytics in logistics and supply chain management: Certain investigations for research and applications	International Journal of Production Economics	2016	839
155	Building new entities from existing titanium part by electron beam melting: microstructures and mechanical properties	International Journal of Advanced Manufacturing Technology	2016	36
156	Deployment of artificial neural network for short-term forecasting of evapotranspiration using public weather forecast restricted messages	Agricultural Water Management	2016	75
157	Dynamic development and execution of closed-loop supply chains: a natural resource-based view	Supply Chain Management: An International Journal	2016	67
158	Machine learning based prediction of soil total nitrogen, organic carbon and moisture content by using VIS-NIR spectroscopy	Biosystems Engineering	2016	296
159	The impact of big data on world-class sustainable manufacturing	International Journal of Advanced Manufacturing Technology	2016	246
160	The Role of Laser Additive Manufacturing Methods of Metals in Repair, Refurbishment and Remanufacturing – Enabling Circular Economy	Physics Procedia	2016	103
161	3D printing for sustainable industrial transformation	Development (Basingstoke)	2015	11
162	An integrated crop and hydrologic modeling system to estimate hydrologic impacts of crop irrigation demands	Environmental Modelling and Software	2015	39
163	Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya	Journal of Cleaner Production	2015	192
164	Co-creation and user innovation: The role of online 3D printing platforms	Journal of Engineering and Technology Management	2015	164
165	The value of big data in servitization	International journal of production economics	2015	365
166	A global sustainability perspective on 3D printing technologies	Energy Policy	2014	575
167	Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm	IEEE international conference on industrial engineering and engineering management	2014	639
168	The big data application strategy for cost reduction in automotive industry	SAE International Journal of Commercial Vehicles	2014	35
169	Flexibility in Reverse Logistics: A Framework and Evaluation Approach	Journal of Cleaner Production	2013	128
170	Mechanical and thermal properties of green lightweight engineered cementitious composites	Construction and Building Materials	2013	172
171	Additive layered manufacturing: sectors of industrial application shown through case studies	International Journal of Production Research	2011	493
172	CO2 sequestration by carbonation of steelmaking slags in an autoclave reactor	Journal of Hazardous Materials	2011	124
173	Comparing machine learning classifiers in potential distribution modeling	Expert Systems with Applications	2011	115
174	Recycling of polyamide 12 based powders in the laser sintering process	Rapid Prototyping Journal	2009	169

Table A2
: Thematic classification of the final dataset.

ID	CSC archetypes				
	Closing	Slowing	Narrowing	Intensifying	Demtaterializing
1	IoT	IoT	IoT		
2			intra-sectorial collaboration, inter-sectorial collaboration, flexibility, visibility; IoT		
3		intra-sectorial collaboration, visibility; IoT	IoT	intra-sectorial collaboration, visibility	
4	AM		AM		
5					BDA, IoT, CC
6		AM	AI, IoT		
7	intra-sectorial collaboration, visibility; IoT				
8	BC	BC	BC	BC	BC
9			visibility		
10			BC		
11	IoT	BDA, AM, IoT	BDA, AM, IoT		BDA, AM, IoT
12			AM		
13	intra-sectorial collaboration, visibility; BC				
14			BC		

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Table A2 (*continued*)

15	visibility, traceability	visibility, traceability			
16	inter-sectorial collaboration, visibility; BC				
17			BC		
18	intra-sectorial collaboration, visibility; BC	intra-sectorial collaboration, visibility; BC	BC		
19	intra-sectorial collaboration, visibility; BC				
20	visibility; IoT	IoT		visibility	
21	intra-sectorial collaboration, inter-sectorial collaboration	intra-sectorial collaboration, inter-sectorial collaboration	intra-sectorial collaboration, inter-sectorial collaboration		
22	intra-sectorial collaboration; BC	BC	visibility; BC	intra-sectorial collaboration; BC	BC
23	AI		IoT		
24			visibility, traceability		
25	BDA	BDA	BDA, AI, AM, IoT, BC		
26			intra-sectorial collaboration, visibility; BC		
27	BDA		BDA, AI, IoT, BC		
28			BC		
29	intra-sectorial collaboration, visibility; BC	intra-sectorial collaboration, visibility; BC			
30	BC, IoT	BC, IoT	intra-sectorial collaboration, visibility, traceability		
31			BC		
32	BDA	BDA	BDA		
33			BDA, AI		
34	IoT	IoT			
35	inter-sectorial collaboration	inter-sectorial collaboration	inter-sectorial collaboration		
36	BC	BC	BC		
37	intra-sectorial collaboration, flexibility	intra-sectorial collaboration, flexibility		intra-sectorial collaboration, flexibility	
38	AI	AI			
39	BC				
40			AI		
41			traceability		
42			BC		
43	BC	BC	BC		
44	BC		intra-sectorial collaboration, visibility, traceability; BC		
45			intra-sectorial collaboration, visibility; BDA		
46			traceability		
47	BC				
48			BC		
49			intra-sectorial collaboration, flexibility, visibility, traceability		
50			traceability		
51			IoT		
52	IoT	IoT	IoT	IoT	IoT
53					AI
54	IoT	BDA, IoT, CC			IoT
55	BC				
56			BC		
57	intra-sectorial collaboration, visibility, traceability; BC	BC	BC	BC	BC
58	IoT		intra-sectorial collaboration, visibility; IoT		
59	intra-sectorial collaboration, inter-sectorial collaboration, visibility	intra-sectorial collaboration, inter-sectorial collaboration, visibility	AM	intra-sectorial collaboration, visibility	
60	BDA, AI	BDA, AI	BDA, AI		
61			intra-sectorial collaboration		
62			AM		
63		intra-sectorial collaboration; BDA, AI, AM, IoT, BC, CC	intra-sectorial collaboration; BDA, IoT		CC
64			intra-sectorial collaboration	visibility	
65			BDA		
66			intra-sectorial collaboration, traceability; BC		
67			intra-sectorial collaboration, visibility; BC		
68			visibility		
69			visibility		
70	BDA, AM	BDA, AM			
71			BDA		
72	BC, IoT				

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Table A2 (*continued*)

73			BC		
74	visibility; BC		visibility; BC		
75			intra-sectorial collaboration, visibility, traceability		
76			intra-sectorial collaboration, flexibility, visibility; BC		
77	BC		BC		
78	intra-sectorial collaboration, visibility; BC	BC	intra-sectorial collaboration, visibility, traceability; BC	intra-sectorial collaboration, visibility; BC	BC
79	AM		AM		
80			BDA		
81			BDA		
82	intra-sectorial collaboration, visibility; BDA	intra-sectorial collaboration, visibility; BDA			
83	intra-sectorial collaboration, visibility; AI, BC				
84	traceability; IoT, BC	IoT, BC	intra-sectorial collaboration, traceability; IoT, BC		
85	intra-sectorial collaboration, flexibility, visibility; IoT, CC	intra-sectorial collaboration, flexibility, visibility; IoT, CC	AM, IoT	IoT, CC	AM, IoT, CC
86			intra-sectorial collaboration, flexibility, visibility		
87	intra-sectorial collaboration, visibility; IoT				
88		AM			
89	flexibility	intra-sectorial collaboration	flexibility, visibility; AM	intra-sectorial collaboration, flexibility, visibility	
90	intra-sectorial collaboration		BDA	intra-sectorial collaboration	
91		intra-sectorial collaboration		intra-sectorial collaboration	visibility
92	flexibility		flexibility	flexibility	
93	IoT	flexibility, visibility; IoT			
94			AM		
95	BC	traceability; BC	BC		
96	AM				
97		AM, IoT			
98	IoT	IoT			
99	BC		BC	BC	
100		BDA			
101	intra-sectorial collaboration, visibility		intra-sectorial collaboration, visibility; BC	intra-sectorial collaboration	visibility
102	BC	BDA	BDA, BC		
103	BC		intra-sectorial collaboration, visibility, traceability; BC		
104			BC		
105			intra-sectorial collaboration, inter-sectorial collaboration, visibility		
106	IoT		IoT		
107			intra-sectorial collaboration, visibility		
108			AM		
109	AM			flexibility	
110			intra-sectorial collaboration, flexibility, visibility		
111		AM			
112	BC				
113	intra-sectorial collaboration; BDA	BDA	intra-sectorial collaboration; BDA		
114			BDA		
115			AM		
116			BDA		
117		BDA	BDA		
118			intra-sectorial collaboration, visibility		
119		flexibility; AM			
120			BDA		
121			AI		
122	visibility; BC	BC	intra-sectorial collaboration, visibility, traceability; BC	BC	
123	intra-sectorial collaboration			intra-sectorial collaboration	
124			intra-sectorial collaboration		
125	AM				
126		inter-sectorial collaboration			
127				AM	AM
128	IoT, CC	IoT, CC	AM, IoT	IoT, CC	AM, IoT, CC

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Table A2 (*continued*)

129			IoT		
130			IoT		
131	AM				
132	AM				
133	AM				
134			AI		
135		AM			
136	inter-sectorial collaboration				
137	AM				
138		IoT			
139	AM				
140	BDA				
141			IoT		
142			AM		
143			AM		
144			visibility		
145				inter-sectorial collaboration; BC	inter-sectorial collaboration; BC
146		AM	AM		
147	AM	AM	AM		
148					IoT
149			BDA		
150	AM	AM	AM		AM
151			AM		
152		AM	AM		
153				Flexibility, AM	AM
154		intra-sectorial collaboration, inter-sectorial collaboration, flexibility, visibility	intra-sectorial collaboration, visibility; BDA		
155	AM				
156			AI		
157	intra-sectorial collaboration, inter-sectorial collaboration, flexibility	intra-sectorial collaboration, inter-sectorial collaboration, flexibility			
158			AI		
159	BDA		BDA		
160		AM			
161			AM		
162			AI		
163	BC				
164				AM	AM
165					BDA
166		AM	flexibility; AM		
167			IoT		
168	BDA				
169	flexibility	flexibility			
170			AM		
171	AM	AM			
172			BDA		
173			AI		
174	AM				

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