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Digital technologies as enablers of circular practices: an organizational perspective

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Abstract

As the circular economy gains momentum, digital technologies (DTs) of Industry 4.0, including big data and analytics, the Internet of Things (IoT), additive manufacturing (AM), and blockchain are emerging as powerful enablers of circular business models (CBMs). These technologies have the potential to enable new ways to perform circular economy practices at both the upstream and downstream levels and to generate significant organizational outcomes. Due to the novelty of the topic, more research is needed to delve deeper into how DTs enable circular practices and impact organizations. This study aims to fill this gap by empirically investigating how DTs 4.0 enable circular practices and exploring the organizational outcomes stemming from their adoption. Through the lens of Italian circular startups, we develop an empirical model that connects specific DTs with organizational outcomes. Our insights bolster the literature on circular entrepreneurship and organizational studies combining DTs and the circular economy.

Keywords: Digital technologies, Industry 4.0, Circular startups

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1. Introduction

Circular Economy and Industry 4.0 have emerged as two of the most influential trends in both industry and academia in recent years (Rosa et al., 2020). Circular Economy (CE) is defined as an industrial system that is restorative or regenerative by intention and design (ibid). Industry 4.0 (I4.0) represents a paradigm encompassing a wide range of concepts that, while not uniquely definable, primarily revolves around digital technologies as main drivers of Industry 4.0. These include the Internet of Things (IoT), big data and analytics, additive manufacturing (AM), and blockchain. These technologies are crucial enablers of circular business models (CBMs) (Antikainen et al., 2018; Bressanelli et al., 2018).

From an organizational studies perspective, the interplay between DTs 4.0 and CE practices not only reflects shifts in business processes but also denotes significant alterations in organizational structures, cultures, and strategies (Castro-Lopez, Iglesias & Santos-Vijande, 2023; Hofmann & Jaeger-Erben, 2020; Plekhanov et al., 2022). The traditional paradigms of how organizations operate, adapt, and innovate are being redefined in light of these converging trends.

CBMs are defined by Geissdoerfer et al. (2020, p.7) as "business models that are cycling, extending, intensifying, and/or dematerializing material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organizational system. This definition includes recycling measures (cycling), use phase extensions (extending), a more intense use phase (intensifying), and the substitution of products with service and software solutions (dematerializing)".

While the influence of DTs on enabling CBMs is a topic of rich and very recent scholarly debate (Centobelli et al., 2020; Liu et al., 2022; Uçar et al., 2020), a distinct gap emerges when considering the organizational dynamics and structures facilitating this integration. Rosa et al. (2020) stress that there is limited knowledge about the types of technologies that can support the implementation of CE, particularly as it pertains to SMEs, which often possess distinct organizational architectures compared to larger entities.

Furthermore, circular startups, while pioneering the introduction of disruptive CBMs and championing sustainable innovations (Bergset & Fichter, 2015), remain underrepresented in discussions from an organizational lens (Bassi & Dias, 2019). The challenges and opportunities these entities face, given their nascent organizational structures and inherent agility, present a unique context that this study aims to uncover.

In response to these observations and heeding the call by Centobelli et al. (2020), this paper adopts organizational lenses to answer the following research questions: how do digital technologies of Industry 4.0 enable the implementation of circular economy practices in circular startups? Which are the organizational outcomes?

Employing a multiple case study methodology (Yin, 2014) with five circular startups as a purposeful sample, we develop and present an empirical model that outlines the relationship between DTs and circular practices. Through this exploration, we contribute to the growing managerial literature enquiring the relationship between DTs and the CE by offering an organizational perspective that is to date missing.

The remainder of this paper is structured as follows. First, we introduce the background literature on DTs and CE as well as our research context, i.e., circular entrepreneurship. Subsequently, we explain the methodology employed and the selected case studies. We then discuss our findings from an organizational perspective, and we propose an empirical research model. We conclude our work by suggesting managerial implications and advancing avenues for future research.

2. Theoretical Background

2.1 Digital technologies of Industry 4.0

Numerous digital technologies (DTs) fall under the Industry 4.0 umbrella (see, for instance, the taxonomy by Berger et al., 2018 and the one by the Boston Consulting Group, 2020). Of these technologies, the IoT and big data and analytics are perceived as the most promising for implementing CBMs (Bressanelli et al., 2018). The IoT consists of “sensors and actuators connected by networks to computing systems” (Manyika et al., 2015, p. 1), enabling “devices to communicate and interact both with one another and with more centralized controllers, as necessary” (Rüßmann et al., 2015, p. 4). The use of big data often refers to “the ability to handle routines in a structured (rather than ad hoc) manner to manage IT resources following business needs and priorities” (Kim et al., 2012, p. 336). Data analytics "leverages software and data mining techniques to extract useful information from data, by developing business intelligence and decision support systems to identify patterns in the data and make predictions" (Bressanelli et al., 2018, p. 21).

Rusch et al. (2023) present a review that provides current and potential examples of DT applications in sustainable product management (SPM). Certain digital solutions, such as digital platforms, blockchain, and IoT, have already been employed to promote circular practices such as reuse, repair, and remanufacturing (Hedberg et al., 2019). Blockchain technology is described as an “online, open-source distributed ledger where transactions between different stakeholders can be recorded and updated simultaneously and in real-time” (Upadhyay et al., 2021, p. 2). For instance, it is increasingly applied to develop circular economy networks (Narayan & Tidström, 2020) and coordinate distributed databases, optimizing the pursuit of the circular economy’s sustainability goal (Upadhyay et al., 2021).

Our study focuses on the aforementioned technologies and additive manufacturing (AM), also termed 3D printing, as it is “promising for sustainable production because the additive and digital nature provides opportunities to save resources” (Sauerwein et al., 2019, p. 1138).

Despite the potential of these technologies to promote circularity, few studies have explored the connection between key Industry 4.0 technologies and CE practices

(Centobelli et al., 2020). Additionally, empirical insights into the potentials of different DTs are lacking (Schöggl et al., 2023).

Additionally, the organizational perspective is largely overlooked (Bassi & Dias, 2019). Our goal is to start bridging these gaps through an empirical investigation of circular startups.

2.2 Digital technologies 4.0 and CE

DTs within the I4.0 classification profoundly affect organizations (Lasi et al., 2014; Liao et al., 2017), facilitating automation and industrial manufacturing in supply chain management and agile and lean production (Agrifoglio et al., 2017). The advantages of using DTs include managing data related to product lifecycles (Li et al., 2015) or enabling smart manufacturing practices (Kusiak, 2018). Such technological advancements are pivotal for transitioning to a more sustainable society (Dubey et al., 2016). Technologies, particularly those under the "Industry 4.0" (I4.0) label (Nascimento et al., 2019), are seen as key enablers of CE business models (Rosa et al., 2019; Massaro et al., 2021) and as mechanisms for boosting circularity in startups and fostering organizational innovation processes toward CE (Bassi & Dias, 2019).
The EU Commission highlights DTs' potential to curtail global CO_2 emissions by 20 percent by 2030 (DigitalEurope, 2020).

Liu et al. (2022) categorize eight functions of DTs that enhance the CE's potential, ranging from monitoring (collecting data to make real-time decisions) and tracking and tracing (collecting information to enable traceability in the value chain) to innovation (discovery and creation, creativity in improving and developing product and service design) and optimization (improving performance and reducing negative impact).

Emerging DTs decisively shape the transition to sustainable innovation and circular practices (Alcayaga et al., 2019; Gligoric et al., 2019). For instance, Ranta et al. (2021) perform a qualitative study based on four circular firms and develop an empirical model that identifies four key types of business model innovation for CE, which are facilitated by DTs. Ingemarsdotter et al. (2020) focus on exploring the opportunities and challenges that stem from implementing IoT-enabled circular strategies. Their findings suggest that the IoT can support four circular strategies, namely, servitized business models, maintenance, reuse/remanufacturing, and design for durability.

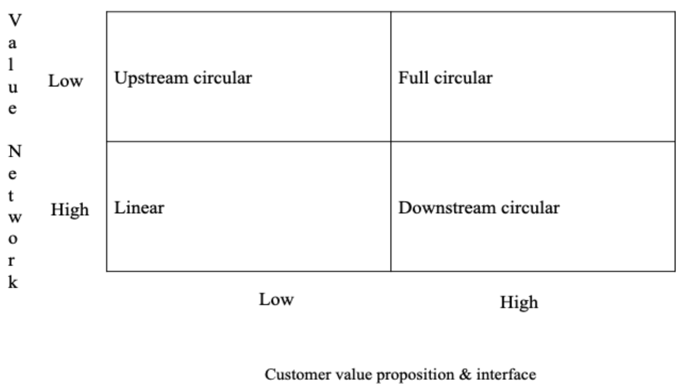
Despite the arousing enthusiasm regarding DTs, the extant literature deals with controversial findings. While some studies laud the potential of these technologies in fostering circular practices (e.g., Bressanelli et al., 2018), others find that environmental benefits are only occasionally evident after adopting I4.0 technologies (Angioletti et al., 2017; Lahrour & Brissaud, 2018; Van Schaik & Reuter, 2016). Thus, the relationship between CE practices and enabling DTs remains ambiguous (Alcayaga et al., 2019; Jabbour et al., 2019; Liu et al., 2022; Okorie et al., 2018). Moreover, it is important to recognize that DTs could exacerbate waste and energy consumption (Chen et al., 2020). Some scholars (Di Maria et al., 2021) caution against potential challenges in harmonizing economic outcomes with sustainability when leveraging technologies such as robotics, 3D printing, and augmented reality. This critical perspective needs to be considered when examining the impact of DTs on organizations.

Nevertheless, there is a consensus in the academic community that DT adoption positively affects organizational performance (Khan & Qianli, 2017). Blockchain technology, for instance, has been found to significantly bolster various CE practices in several dimensions, such as procurement, circular design, recycling, and remanufacturing, which in turn enhance organizational performance (Khan et al., 2021).

2.3 Theoretical frameworks and circular startups

Urbinati et al. (2017) proposed the concept of "degree of circularity" to differentiate between linear, upstream, downstream, and fully circular firms (see Figure 1).

Figure n. 1 - The four modes to adopt CE principles.



Source: Adapted from Urbinati et al. (2017).

The two key variables considered are customer value proposition and value network. The former refers to the concept of circularity in proposing value to customers, while the latter concerns the ways by which companies interact with their suppliers and reorganize their internal activities, namely, key resources, activities, and upstream partners (Osterwalder & Pigneur, 2013).

Linear firms adhere strictly to a linear economic model, bypassing the principles of circularity. Upstream circular firms incorporate these principles into their internal activities, such as product design, and extend them to their relationships with suppliers. These firms might, for instance, collaborate with suppliers to utilize secondary or recovered raw materials in their production processes. However, these circular practices remain confined within the organization and do not extend to customer interactions.

In contrast, downstream circular firms emphasize circularity at the customer level, often promoting product reuse and other related practices. The communication of these circular practices to customers is pivotal because they offer tangible value. Full circular firms integrate circular practices at both the upstream and downstream levels, fully embracing the concept.

While Urbinati et al.'s (2017) framework provides a structured categorization of firms based on their degree of circularity achieved through circular practices, it does not delve into the role of DTs in enacting CE practices. This area represents a noticeable research gap, which Centobelli et al. (2020) sought to address. They introduced the idea that implementing DTs is a fundamental cross-dimensional managerial strategy that promotes value creation and capture within a CBM.

Building on these frameworks, our research empirically investigates how DTs can be used to implement circular practices at both upstream and downstream levels by focusing on circular startups as our unit of analysis. As defined by Henry et al. (2020, p.3), start-ups are "new -, i.e., typically operating for four to six years - and 'independent' entrepreneurial ventures designed to effectively develop and validate a scalable, repeatable and at least break-even business model". Circular startups are unique in that they "adopt CBMs from the start, take a holistic perspective at their business model and monetize design-to-last and maintenance efforts" (ibid.). These startups, with their disruptive nature, are gaining growing academic attention (Prosman & Cagliano, 2022; Von Kolpinski, 2022) and are seemingly predisposed to explore DTs in implementing their CBMs.

Integrating digital technologies also generates organizational outcomes, for instance, in intra-organizational structuring, since organizations develop agile structures and become increasingly adaptable and boundaryless (Schwer & Hitz, 2018). The digitization process within organizations also generates automatized and data-driven business processes (Dery et al., 2017) and fosters the development of smart and customized products (Porter & Heppelman, 2015). Our investigation aims to further understand the implications of DTs, culminating in a comprehensive organizational perspective on the adoption of DTs in CE practices (Hanelt et al., 2021; Poole & Van de Ven, 2004).

3. Methodology

3.1 Data collection

This exploratory study investigates (i) the types of digital technologies of Industry 4.0 (i.e., IoT, big data and data analytics, blockchain, and AM) employed by circular startups, (ii) the circular practices enabled by DTs, (iii) the degree of circularity reached through DTs, and (iv) the related organizational outcomes (the impact that the adoption of DTs has on organizations).

Given the exploratory nature of our research (Patton, 1989), we opted for a qualitative multiple case study methodology (Eisenhardt, 1989; Yin, 2014), which often yields insights that are particularly relevant to practitioners (Amabile et al., 2001; Leonard-Barton, 1990). Throughout the study, we adhered to transparency criteria and best practices for qualitative research (Aguinis & Solarino, 2019) in both data collection and analysis.

Italy was chosen for the study because it leads the circular economy movement among major European economies, boasting a recycling rate of 72% (compared to the European average of 53%) and a circular material use rate of 18.3% (versus 11.8% in Europe) (Circular Economy Network & Enea 2023). Furthermore, Italian companies present levels of digitalization in line with the EU average, but there is a gap between large companies (62%) and SMEs (19%) (Istat, 2023[1]). This provides an opportunity to explore how digital technologies can improve circular practices, especially in startups and SMEs, while simultaneously contributing to the EU's 2030 digitalization goals. Italy also has a significant representation in the circular start-up index by the EllenMacArthur Foundation[2].

Our initial data collection began with secondary data such as third-party interviews and reports showcasing circular startups employing DTs 4.0, such as the Italian "Atlante Storie di Economia Circolare[3]"

We identified firms based on three main criteria: i) the firm utilizes at least one of the major digital technologies of industry 4.0 recognized in the literature as an enabler of circular practices (IoT, big data and data analytics, blockchain, and AM); ii) the firm adheres to one of the recognized circular business models, such as circular supply chain, resource recovery and recycling, product life extension, sharing, or product as a service (Lacy & Rutqvist, 2014), ensuring a diverse representation across industries and adopted digital technologies. (iii) Finally, the availability of the startup founders or, if not, the most knowledgeable informed individuals within the venture (Eisenhardt & Graebner, 2007) for an in-depth semi-structured interview.

Applying these criteria, we narrowed our focus to ten startups. We reached out via email to confirm the availability of the respective founders for interviews. Of the ten, five firms consented, forming our final sample. Data collection spanned two months, specifically September and October 2022.

Prior to each interview, the questions were emailed to the participants, allowing them time for reflection. The interview rotated around these main questions: "What types of digital 4.0 technologies do you use? For which purposes?", "Which circular activities do you perform through digital technologies?" and "Could you explain in detail if and how digital technologies enable circular activities at the upstream and/or downstream levels?". Table 1 provides an overview of the five case studies and related interviewees. Each semi-structured interview, ranging from 30 to 40 minutes, was recorded via Zoom and transcribed within 24 hours**.** Notably, interviews were conducted in Italian – the native language of the interviewees - and subsequently

[1] https://www.istat.it/it/archivio/279478
[2] https://ellenmacarthurfoundation.org/resources/business/circular-startup-index
[3] https://economiacircolare.com/atlante/

translated into English post-transcription. To bolster internal validity (Denzin, 1978), we triangulated our primary data with secondary sources, including second parties' interviews, web articles, and social media pages. Furthermore, investigator triangulation was employed, meaning that our research team compared data analysis until consensus was reached (ibid.). Throughout the process, we also strictly adhered to established ethical research principles (Kvale, 1995).

Table n. 1. Selected firms. Key facts and figures.

Company name	Interviewee (role)	Industry	Country and Year of Foundation	Circular business model	N. employees	Type(s) of Digital technologies	Circular mission	B2C/B2B
PCUP[1]	Stefano Fraioli (founder)	Digital services	Italy, 2018	Product-life-extension	9	IoT	"We offer reusable glasses to all the clients that desire an alternative to the disposable glasses. The PCUP glasses are flexible, resistant and have a high-tech component that make them a source of data, a payment method and a way to build social relations".	B2B and B2C
Seay	Alberto Bressan (founder)	Textile	Italy, 2018	Recovery and recycling	3	Blockchain	"SEAY draws, produces, and distributes beach wear, accessories for men and women at high technological value by using textiles and technologies which require the recycle of plastic and waste materials, with the aim to minimize the environmental impact and to improve the quality".	B2C and B2B

[1] This firm closed in November 2022 due to the lack of investments to scale up.

Krill Design	Martina Lamperti (Project Manager and Designer Coordinator)	Additive manufacturing	Italy, 2018	Circular input	3	3D printing	"Krill Design is an Italian design studio specialized in the development of new design products within a 100% circular and sustainable process"	B2B and B2C
Replicami	Alessio Bigini (founder)	Additive manufacturing	Italy, 2018	Product life extension	2	3D printing	"Replicami.it is a young Tuscan start-up that offers a replication service through the 3D printing of any object, thus contributing to a circular economy based on re-use and recycling"	B2B and B2C
Atelier Riforma	Elena Ferrero (co-founder)	Technologies	Italy, 2020	Circular input	2	AI	"Atelier Riforma started from an unconventional idea: create a network of tailors, designers and social tailors who dealt with transforming discarded garments to give them greater value and put them back into circulation on a sales platform"	B2B

Source: own elaboration

3.2 Data analysis

Initially, we conducted a single-case analysis and subsequently performed a cross-case comparison to discern both similarities and disparities among the cases (Eisenhardt, 1989). Using an abductive approach, we intertwined empirical observations with existing theoretical frameworks, thereby deepening our understanding of both the theoretical concepts and the empirical phenomena in focus (Dubois & Gadde, 2002).

Guiding our data analysis, we identified three key variables, namely, i) digital technologies employed; ii) circular practices enabled by digital technologies and achieved degree of circularity; and iii) organizational outcomes.

Our analysis was carried out manually. We began by categorizing statements from interviewees based on the aforementioned variables. The initial phase involved a within-case analysis, after which we advanced a cross-case examination.

We finally proposed an empirical model linking DTs with the degree of circularity reached thanks to these technologies both at the upstream and downstream levels.

4. Findings

4.1 Within-case analysis

We present the single case analysis of our case firms, spotlighting the DTs each firm adopts and the circular practices these technologies foster. We also emphasize the degree of circularity achieved and the organizational outcomes.

4.1.1 PCup

Founded in 2018 by Lorenzo Pisoni and Stefano Fraioli, PCup emerged with the vision of supplanting disposable drinkware with smart, reusable alternatives while simultaneously collecting [big] data on consumer beverage consumption.

Their offering is a durable, food-grade silicone cup that withstands washing, UV exposure, detergents, extreme temperatures, and dishwasher cycles.

Our interviewee illustrated the inception on PCup: "Lorenzo Pisoni was kayaking in Corsica and observed the sea's litter predominantly composed of plastic cups. From there, he began to reflect on this waste, on pollution caused by cups. Then, in the evening, arriving in the city center with friends, he noticed that in all places where there is conviviality, there are cups."

Here comes the connection between the cup as a tool for socializing and the role of technology in potentially enhancing sustainability. Disposable cups are often viewed as having little value beyond their contents, but technology may be able to give them

added value and facilitate connections between people. Otherwise, disposable cups only allow connections through the drink they contain.
Unlike typical reusable cups that endure a mere 100 washes, PCup's variant boasts resilience beyond 2,000 washes, championing circularity via a prolonged lifecycle.

a) Digital technologies employed

PCup integrates technology to enhance user experience and bolster the circular economy. Harnessing the IoT, they envision cups as more than mere vessels: repository of information, data, and multiple uses. "Lorenzo's idea was born from the desire to create a cup that was first and foremost reusable, in order to eliminate the pollution in the seas and to make it reusable thanks to a technology (NFC).

Through the use of IoT, it is possible to give a second life to these objects because a disposable cup, after use is thrown away, but a cup that can have a higher intrinsic value [...] is no longer disposable."
PCup incorporates an array of digital tools, including NFC chips, QR codes, and cloud-based software. These digital technologies enable PCup to collect and analyze big data on beverage consumption and cup usage, which contribute to improving circularity by offering insights into usage patterns, optimizing inventory, and minimizing waste at the downstream level.

As stated by our interviewee, "big data is important for real-time decisions: if I can understand in an event how the crowd moves within an event/festival, I can then manage the event in the best way, I can encourage the return of our cups".

b) Circular practices enabled by digital technologies and achieved degree of circularity.

Building on their commitment to circularity, PCup collects used cups from businesses, recycling them into synthetic oils or new cups. They "offer an additional circularity service to [their] customers [which is] to pick up the cup park (lots of cups) and start them for disposal and reuse to be transformed into synthetic oils for other productions or for other cups cast for a lower percentage of silicone."

This service p circularity at the downstream level, as it allows for the reuse of the cups rather than them being disposed of. However, at the upstream level, PCup does not maintain a circular production system, as they use raw materials to craft the silicone cups.

The IoT technology embedded within the cups not only facilitates tracking of consumption data but also monitors the whereabouts of the cups, enabling PCup to retrieve them post events. Leveraging this technology, PCup achieves downstream circularity by collecting and recycling used cups. They offer to retrieve used cups from local businesses and events to recycle them, either repurposing them into synthetic oils for production or casting them into new cups. This approach closes the lifecycle loop of the cups by recovering and reusing materials that would otherwise be discarded as waste.

c) Organizational outcomes

PCup's adoption of digital technologies, including NFC chips, QR codes, and cloud platforms, generates profound organizational shifts, emphasizing data-driven decision-making that permeates inventory strategies and waste reduction efforts. This pivot toward data analytics revolutionizes their supply chain via IoT, enhancing real-time monitoring and optimizing the logistics of collection and recycling. Such technological integration not only refines operations but also triggers diversification in their business model, melding tech with circular principles to boost revenue and market presence. Organizational values are now deeply rooted in data literacy and sustainability, signaling the inception of roles focused on data analytics and a revamp in HR strategies. As PCup champions environmental sustainability, it necessitates robust governance mechanisms, especially in managing ties with event organizers, thus accentuating interorganizational collaboration. Within this digital transformation, PCup underscores the criticality of IT for data handling while concurrently prioritizing data security and privacy.

4.1.2 Seay

Seay, an Italian fashion enterprise, champions sustainability in the textile sector through its circular business model and its RE3 circular system. Its origin traces back to manufacturing swimwear and apparel from regenerated materials and has expanded its offerings to include recyclable fiberglass furniture for retail stores. The RE3 model acts as a platform dedicated to the recovery, management, tracking, and repurposing of used textiles.

To further its commitment, Seay introduced a subsidiary, RE3 srl, focusing on end-of-life management services for used items, leveraging blockchain technology for both B2C and B2B segments.

a) Digital Technologies Employed

Seay's RE3 model employs multiple digital tools to enhance its circular practices. Central to this is the use of QR codes, which are pivotal for monitoring the movement and reuse of repurposed clothing and textiles throughout the RE3 cycle. As Bressan notes, "Our platform is able to generate QR codes and we print them internally, we apply them to various types of supports such as internal tags on garments or they are printed at the cash register with a receipt and from there the customer has a QR code for tracking." Additionally, the model integrates blockchain technology, ensuring the traceability and certification of each garment’s lifecycle. In a collaborative venture, Seay partnered with a blockchain-centric provider, leading to the creation of a traceability system. Every item now has an “identity card”, allowing Seay to oversee the responsible closure of its lifecycle.

b) Circular practices enabled by digital technologies and achieved degree of circularity.

The RE3 model empowers "prosumers" to return old clothes. The latter are tracked and managed by different actors, i.e., a social cooperative, a regeneration company, and a blockchain service provider. This structured traceability ensures the responsible closure of each garment's life cycle. Seay ambition is to establish a virtuous circle, fostering deeper engagement with its clientele and encouraging the return of garments that are either unwanted or no longer in use. The inclusion of digital technologies in Seay's RE3 model allows the company to transparently manage and monitor textile movements, making the process accessible for B2B and B2C customers alike. Such transparency nurtures trust, potentially increasing participation in the circular economy. Echoing this sentiment, Bressan observes, "The RE3 model is used by the consumer to see what happened to the garment, by the company for tracking and by us to manage everything." Blockchain integration ensures that each garment's lifecycle is traceable and certifiable, a cornerstone for circular business model success.

Although Seay predominantly focuses on the downstream level by leveraging blockchain-based item tracking, a recent partnership with ID Factory has enabled them to extend the RE3 system's process to B2B clients and involve the supply chains, thus also enhancing upstream activities.

c) Organizational outcomes

The establishment of RE3 srl, Seay's spinoff, combined with strategic blockchain partnerships, signals organizational diversification. Operational facets are transformed with QR code integrations for meticulous item tracking, prompting the augmentation of IT infrastructure and the creation of specialized lifecycle oversight teams. Seay's culture sees sustainability, transparency, and authenticity at its core, backed by blockchain technology. Their expanding collaborations, from regeneration companies to blockchain service providers, not only widen external networks but also redefine customer engagement with an emphasis on "prosumers". Central to this transformation is a fortified information system, where QR and blockchain technologies are pivotal, demanding a steadfast commitment to data security and integrity. Given blockchain's decentralized architecture, Seay's governance might lean toward distributed decision-making. Human resources now pivot toward expertise in blockchain and QR management, with emphasis on recruitment and training. The cornerstone remains transparent traceability, enabled by QR codes and blockchain, offering a comprehensive view of a garment's journey and fostering trust among B2B and B2C stakeholders. The RE3 model, symbolizing end-to-end lifecycle management, resonates with Seay's sustainable commitment. This system's flexibility, evidenced by collaborations such as that with ID Factory, displays adaptability across the supply chain.

4.1.3 Krill Design

Krill Design is a start-up established in 2018, stemming from an idea by Ivan Calimani to innovatively utilize 3D printing with organic materials as production input. To bring this vision into life, the founder initially assembled a team, including our interviewee, Martina Lamperti, who possessed not only expertise in 3D printing but also in product design and modeling tailored for 3D printing constraints. While the company's initial focus was on fabricating a biomaterial from potato waste for 3D printing, challenges arose in converting this material into usable form. As our interviewee recounted, "The biomaterial from potato waste has remained somewhat on "standby by" because we probably did not have enough knowledge to transform it into a material that could be used to print in 3D. The material was not working well, especially with humidity."

In April 2019, Krill Design entered into a partnership with Autogrill, an Italian-based multinational catering company. This collaboration led to the development of the ReKrill Orange biomaterial, sourced from the waste of Autogrill's orange juice. The innovative material was used to manufacture sugar packet holders displaced in Autogrill stores. Collaboration with Autogrill is ongoing, with both entities exploring product opportunities for a circularity-centric corner in Autogrill stores.

Furthermore, Krill Design pioneered a biomaterial derived from coffee waste (Coffee. Era), which became central to a joint initiative with the Municipality of Milan and engaged students from the Faculty of Design at the Polytechnic University. This biomaterial was fashioned into products available in various Milanese bars and restaurants. As Krill Design's portfolio explanded, collaborations blossomed with firms such as SanPellegrino and Cimbali, capitalizing on biomaterials from orange and coffee waste. More recently, the company has also developed a biomaterial from lemon waste.

a) Digital Technologies employed

The digital technologies employed by Krill Design enable circular activities at both the upstream and downstream levels of the company's operations. At the upstream level, 3D printing technology facilitates the conversion of waste materials into utilizable biomaterials, effectively closing the waste loop and curbing reliance on virgin resources. The team meticulously predesigned objects to align seamlessly with 3D printing, minimizing resource waste and postproduction time. Boasting a fleet of approximately 40 printers, Krill Design even customizes or enhances some machines in-house to process their unique biodegradable input materials.

At the downstream level, the firm is venturing into e-commerce to market products directly to its audience. Nevertheless, the most significant step for closing the loop occurs at the product end-of-life.

As Lamperti elucidates, there are dual routes for material retrieval postuse: "[…] return of end-of-life products, we can shred them and make new material. Therefore, all the prints that come out badly or even all the test prints that we do (all print waste) we can (and already do) shred them and have new material. Alternatively, the final products can be thrown into the wet waste.” The materials do not naturally degrade but start decomposing when introduced to specific environments, such as being buried in soil.

b) Circular practices enabled by digital technologies and achieved degree of circularity.

The inherent circularity of 3D printing lies in its ability to create functional items while mitigating fresh resource extraction. Krill Design envisions diversifying its biopolymer range and fostering ties with businesses producing transformable byproducts. Through these endeavors, the company seeks to reinstate the purpose of these byproducts and return the repurposed products to their original waste-generating firms. The company develops circularity both at the upstream and downstream levels. However, it is pivotal to recognize that while 3D printing is integral to the upstream phase, the downstream level is mainly managed via e-commerce. In this landscape, I4.0 technologies, particularly 3D printing, primarily influence the production phase (upstream level). These innovations breathe life into products, which eventually find their way to B2B clientele or end-users through digital commerce platforms. These technologies are employed to manufacture the objects, which are then displayed or sold in B2B customer stores or through e-commerce to final consumers.

c) Organizational outcomes

Krill Design's adoption of digital technologies has profound organizational outcomes in championing circular economy practices. Their strategic collaborations with industry giants reflect a vision that intertwines growth with sustainability. The emphasis on specialized 3D printing technologies suggests a potential organizational shift toward dedicated operational units, emphasizing adaptability in the face of challenges such as potato waste biomaterial predicaments. Culturally, Krill’s integration of innovation and sustainability is strengthened by academic collaborations, such as with the Polytechnic University. Supporting their e-commerce aspirations demands not only robust digital infrastructure but also a specialized talent pool adept at 3D printing, biomaterials, and digital outreach. This tech-driven approach amplifies Krill’s commitment to circularity, requiring both consumer incentives for returns and strict quality controls. Such technological strides promote an internal culture of continuous upskilling. Krill’s holistic approach, characterized by innovative 3D printing and e-commerce ventures, crystallizes their overarching vision for a sustainable, circular economy.

4.1.4 Replicami

Replicami is an Italian 3D printing project, stemming from MakerHouse, a limited liability company born in 2018 and specializing in 3D printing and modeling for the medical sector. Replicami leverages both 3D printing and 3D scanning technologies to craft spare parts for damaged objects. Its core clientele comprises B2B sectors, including industrial automation manufacturing, fashion, and architectural design. In 2021, the firm became an LLC, and it is currently expanding in the B2C sector as well. However, the main clients are mainly companies selling service household appliances or making spare parts and offering repair services through reverse engineering processes. Some examples of clients are Toyota, which asks the firm to make components that are no longer available on the market, or assistance centers for household appliances that are in need of "out-of-commerce" parts. The firm currently does not manage the end-of-life of products; however, it usually sends finished cartridges and coils to suppliers to be recycled, thus contributing to the creation of a circular economy.

a) Digital Technologies Employed

Replicami primarily utilizes 3D printing as its chief digital technology. This technology allows the company to reproduce broken spare parts for objects, thus prolonging the lifespan of such objects. For example, Replicami can use 3D printing to create spare parts for appliances that are no longer in production. Their approach emphasizes sustainability, printing "on demand" to minimize material waste and eliminating the need for storage. Furthermore, Replicami's capabilities extend to using recycled or biodegradable materials for their spare parts, making a significant stride in environmental conservation and impact. However, these recycled materials often present printing challenges due to their varied properties. While Replicami does not develop materials in-house, they collaborate with centers, including those in Zurich, for testing new materials and offering constructive feedback, especially regarding biomaterials. Replicami lacks the capability to develop materials internally. They maintain connections with centers such as Zurich, which offer them the opportunity to test new materials and provide feedback to contribute to the development of biomaterials.

b) Circular practices enabled by digital technologies and achieved degree of circularity.

The circular practices enabled by Replicami's digital technologies include the refurbishment and reproduction of spare parts for damaged objects. According to the founder, "with Replicami, we also want to expand to B2C, it is a service mostly for companies that need spare parts because they provide customer service." Replicami collaborates with suppliers to test and use recycled materials in its 3D printing processes and demonstrates its commitment to the upstream circular process by incorporating recycled materials in its 3D prints. However, there is a learning curve, as noted by our interviewee: "recycled materials have "worse" printing characteristics, so they require more testing, more experience and not everyone can print them."

Despite these initiatives, Replicami faces challenges in achieving full circularity. Postsale, the company remains unaware of the component's fate. A practical step they have undertaken in this direction is incentivizing customers to return empty cartridges and rolls in exchange for discounts. Such practices not only deter waste but also foster an internal circular process.

The degree of circularity reached through Replicami's digital technologies involves mostly the upstream level, as the company focuses on producing spare parts for damaged objects to extend their lifespan. Collaborative efforts with suppliers to infuse recycled materials into 3D printing further amplify their upstream-level circular initiatives. Nonetheless, a full degree of circularity remains elusive, as Replicami has not fully addressed the end-of-life phase of its components.

c) Organizational outcomes

Replicami's embrace of on-demand 3D printing has transformative organizational outcomes. Their operational model, driven by agile printing, hints at reduced storage infrastructures and a flexible production approach. Partnering with external centers such as Zurich implies a strategic organizational pivot toward collaborative innovation. This collaboration, coupled with a diverse B2B portfolio, suggests a multifaceted and adaptive client relations strategy. The integration of dual 3D technologies within their framework demands the establishment of specialized training and equipment maintenance units. Their endeavors with recycled materials, despite challenges, signal an unwavering commitment to sustainability, potentially influencing R&D directions. The governance structures they have employed to manage partnerships underline the need for meticulous coordination. As they view the B2C market, one can anticipate shifts in their marketing, service, and customer relations departments. Overall, Replicami's trajectory showcases an organization constantly adapting, both technologically and structurally, to meet its circular economy aspirations.

4.1.5 Atelier Riforma

Established in 2019, Atelier Riforma is an innovative startup with a social mission. The company initially operated with a business model where they collected used clothes in a warehouse, curated them with the help of tailors, designers, and social tailor shops, and subsequently sold these refurbished garments via an e-commerce platform. However, in 2021, they recognized the scalability limitations of this model and pivoted toward the development of a technological solution. The outcome is the inception of RE4 circular, a technological tool provided to firms as a means to catalog and digitalize used clothes. Deployed primarily to entities that gather used clothing, this technology allows them to harness garment-related data and vend the clothes in bulk on the platform to diverse buyers such as vintage stores, textile recycling companies, and professionals/craftsmen brands that do upcycling. Atelier Riforma earns by claiming a percentage from each transaction processed on the platform. The company's main objective is to scale the circular management of used clothes and prevent clothing from ending up in landfills or being incinerated.

a) Digital technologies employed

Atelier Riforma's technological pivot led to the development of "RE4 circular," an AI-driven platform focusing on cataloging and digitizing used clothes. With an aspiration to offer a technological ally to firms for promoting a circular clothing lifecycle, they conceptualized and brought RE4 circular to life. Once deployed, businesses can photograph clothing items, extract key garment details, and establish a digital replica.

Serving dual purposes, the platform also acts as a marketplace, bringing together different stakeholders and facilitating the sale and purchase of used clothes. As emphasized by the founder, their core strength remains the "technology and marketplace platform because it brings different players together and allows for a sale and purchase of these clothing items to take place." The digital technologies employed by Atelier Riforma therefore include AI technology for cataloging and digitalization of used clothes, as well as a marketplace platform for facilitating the sale and purchase of these refurbished clothes.

b) Circular practices enabled by digital technologies and achieved degree of circularity.

The digital innovations by Atelier Riforma seed circular practices at multiple levels. It enables circular practices such as the collection and sorting of used clothes at the upstream level and the sale and purchase of these clothes to various circular fashion companies and professionals at the downstream level. At its core, the RE4 circular platform uses AI to let businesses generate a digital catalog for used garments, encompassing images, labels, and other essential attributes. Serving as a junction, it ties these businesses with a plethora of potential buyers, such as thrift stores, textile recyclers, and upcycling artisans. This consolidated marketplace ensures that garments find a new purpose, advocating for expansive circular clothing management.

This transformative approach, built on AI, was realized through a strategic shift, as captured by one of our interviewees: "we have hired three boys who are three data scientist engineers who had already made a proof of concept last spring. We were waiting to receive some funds to start the structural development of this part of artificial intelligence".

RE4 circular's model champions circular practices by bridging the gap between demand and supply for used clothes, simplifying their trade, and ensuring garments find sustainable endpoints.

Through the RE4 circular, Atelier Riforma achieves commendable circularity both upstream (collection and curation) and downstream (resale to circular fashion stakeholders).

By integrating AI technology and a comprehensive marketplace, the platform offers a streamlined process for B2B entities dealing with used garments, ensuring that the life of clothing is extended through appropriate channels.

c) Organizational outcomes

Atelier Riforma's strategic pivot from direct resale to a technology-driven platform necessitates profound organizational shifts. This transition, driven by market responsiveness, underscores a reconfiguration in business processes, demanding robust IT infrastructure, cybersecurity, and consistent technological upgradation. This technological shift also hints at an evolving corporate culture valuing waste prevention, innovation, and adaptability. Integrating AI and a dual-purpose platform accentuates the need for a tech-focused workforce, suggesting potential HR strategies geared toward hiring and upskilling in tech roles. Their new commission-based financial model implies the introduction of refined tracking systems, forecasting tools, and transactional transparency. Externally, diversifying partnerships — ranging from vintage stores to craftsmen —signals a broader engagement and trust-building strategy. As they reposition as a tech ally in a circular fashion, their marketing approach and governance structures, including user agreements and policies, must adapt. Atelier Riforma's rapid adaptability and feedback-driven enhancements highlight their commitment to maintaining platform relevance within the circular economy's digital landscape.

4.2 Cross-case comparison

In this section, we perform a cross-case comparison of our case studies to look for recurring patterns and key differences. The cases are analyzed with respect to our key variables of interest: "Digital Technology employed", "Circular practices enabled by DTs and degree of circularity reached through DTs" and "Organizational outcomes" (Table 2).

Table 2. Cross-case comparison.

Firm	Digital Technology employed	Circular practices enabled by DTs and degree of circularity reached through DTs	Organizational outcomes
PCUP	IoT	-Reduce costs and increase revenues of clubs, bars, restaurants, festivals, catering through reusable cups by collecting and analyzing consumption data and making real-time smart decisions such as disposing the bins in the most appropriate location to collect cups after the events. <u>Operational aspects</u> - Optimize the supply of cups according to data about consumption and glass replacement needs (limit waste) - Send info to final clients and allocate the rubbish bins for cups where they can be found according to real time data (product take back) DATA FOR OPTIMIZING REAL-TIME DECISION MAKING FOR PRODUCTS' TAKE-BACK DEGREE OF CIRCULARITY: Downstream level: managing the return of reusable cups from consumers.	-Organizational culture focused on data analytics capabilities. -Data enables an efficient, tech-centric supply chain. <u>Operational aspects</u> -Refinement of collection and recycling logistics. -Training and management of employees focused on data analytics. ORGANIZATIONAL CULTURE FOCUSED ON DATA AND SUSTAINABILITY HR DEVELOPMENT (SKILLS AND COMPETENCES) SUPPLY CHAIN OPTIMIZATION
Seay	Blockchain	-Create a "digital ID" of the items from the very beginning of the value chain (production) <u>Operational aspects</u> -Manage the take-back of old items from final customers to the firms, ensuring transparency along the reverse process (track and manage the product take back)	-Creation of a spin-off, RE3 srl, suggesting changes in the organizational structure -Strong emphasis on sustainability and transparency as key components of the organizational culture. -Adoption of blockchain technology underscores the value of transparency and authenticity in the organization's ethos. <u>Operational aspects</u>

		-Track the items along the path from givers to the final buyers/receivers to ensure transparency (tracking to ensure transparency) TRANSPARENCY, MANAGING THE REVERSE FLOW OF ITEMS DEGREE OF CIRCULARITY: Upstream level: collecting and sorting used or not worn clothes, reuse of clothes and textiles. Downstream level: resell, refurbish, tracking and management after sale, traceability, and certification	-Training staff to understand and manage blockchain and QR code systems. -Recruiting specialized talents focused on digital technology management. -Enhanced control mechanisms to ensure the accuracy and legitimacy of data captured in the blockchain. ORGANIZATIONAL CULTURE FOCUSED ON SUSTAINABILITY AND TRANSPARENCY, HR DEVELOPMENT (SKILLS AND COMPETENCES) ORGANIZATIONAL STRUCTURE CHANGES
Krill Design	AM	-Employing organic materials from waste processes or PLA bioplastics derived from corn starch (from supplier) to make new objects <u>Operational aspects</u> - “Just in time” production avoiding waste through 3D printing technology EMPLOYING WASTE MATERIALS TO MAKE NEW OBJECTS DEGREE OF CIRCULARITY: Upstream level: use organic waste materials as a production input for 3D printers	-Agility and flexibility in operations. -The introduction of unique 3D printing technologies tailored for specific biodegradable materials implies potential for specialized operational units or teams. -Emphasis on sustainable and innovative solutions, fostering a culture of innovation and ecological responsibility. -This tech-forward approach might foster a culture of continuous learning and adaptability within the organization. -Need for specialized talent familiar with 3D printing constraints, biomaterial development, and digital marketing (given their e-commerce approach). -Control mechanisms to assess the quality and viability of biodegradable materials for 3D printing. <u>Operational aspects</u> -Procurement of raw materials from partners’ waste (e.g., Autogrill) as input for ReKrill bioproducts. ORGANIZATIONAL CULTURE FOCUSED ON SUSTAINABILITY & INNOVATION HR DEVELOPMENT (SKILLS AND COMPETENCES) SUPPLY CHAIN OPTIMIZATION

Replicami	AM	-3D printing and 3D scanning technologies to produce spare parts for broken objects by using biodegradable, recyclable, or non-recyclable materials to augment the lifespan of the objects. <u>Operational aspects</u> - “On demand” production avoiding waste through 3D printing technology - Employing eco-sustainable materials PRODUCTION OF COMPONENTS TO INCREASE THE OBJECTS’ LIFESPAN DEGREE OF CIRCULARITY: Upstream level: use of recyclable input from suppliers to test and use recycled materials”; “we do not throw away empty cartridges and rolls, we sell them to the supplier in exchange for a discount”). Downstream level: increase objects’ life by replacing their broken components	-Strong emphasis on innovation and R&D at the core of organizational culture. -Control mechanisms to assess the quality and longevity of printed spare parts, especially when using recycled materials. <u>Operational aspects</u> -Hiring specialized talents with skills and competencies concerning 3D printing ORGANIZATIONAL CULTURE FOCUSED ON INNOVATION HR DEVELOPMENT (SKILLS AND COMPETENCES)
Atelier Riforma	AI platform	-AI platform for cataloging and digitalizing used clothes provided to B2B entities (e.g., profit, non-profit, cooperatives) -Allows the process of collecting and sorting used clothes coming from bins scattered throughout the territory and/or managing the process of unsold garments in their warehouse. <u>Operational aspects</u> - Development of a technology for cataloging and digitizing used clothes, which is provided to all those B2B actors that deal with collecting used clothes. CATALOGING AND DIGITALIZING THE SORTING AND SALES PROCESS DEGREE OF CIRCULARITY: Upstream level: collection and sorting of used clothes. Downstream level: sales and purchase of these clothes	-DTs enable an efficient supply chain. -Preventing waste influences organizational values, principles, and employee motivation. - Emphasis on innovation and adaptability. <u>Operational aspects</u> - Integration of AI indicates the need for recruitment processes focused on tech expertise. -Continual need for upskilling and training to keep up with evolving technological solutions. ORGANIZATIONAL CULTURE FOCUSED ON SUSTAINABILITY & INNOVATION HR DEVELOPMENT (SKILLS AND COMPETENCES) SUPPLY CHAIN OPTIMIZATION

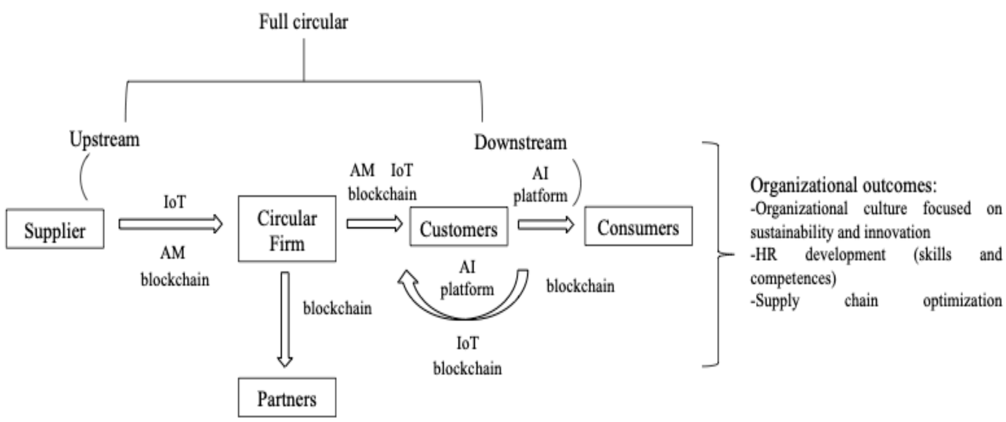
Source: own elaboration.

5. Discussion

The cross-case comparison allows us to elaborate our key findings, which are consistent with the literature reporting that DTs favor circular practices (Alcayaga et al., 2019; Gligoric et al., 2019), yet they also go deeper to investigate how DTs enable the said circular practices (Centobelli et al., 2020; Liu et al., 2022). Centobelli et al. (2020) introduced the key concept that digital technology implementation is a cross-dimensional managerial practice for value creation and capture. Responding to their call for investigating the ways in which DTs can enable circular practices, we find five possibilities, namely, i) data collection and analysis for optimizing real-time decision making to enable products' take-back, ii) transparency and management of the items' reverse flow, iii) employment of waste materials to make new objects, iv) production of components to increase the objects' lifespan, and v) cataloging and digitalizing the sorting and sales process.

The cross-case comparison enabled us to also analyze the organizational outcomes stemming from DT integration and to finally advance an empirical model of digital technologies and organizational outcomes (Figure 2).

Figure 2. An empirical model of digital technologies and organizational outcomes.



Source: Own elaboration.

In line with the study by Khan et al. (2021), we find that blockchain technology enables various CE practices in many dimensions, for instance, managing and tracking reverse logistics operations.

We add to the authors' findings that blockchain technology fosters the implementation of circular practices at both the upstream and downstream levels while concurrently providing transparency along the reverse process flow including partners (upstream level) through product tracking and management (downstream level). We can therefore infer that the more blockchain technology is integrated along the value chain, the more a circular firm can implement circular practices at both the upstream and downstream levels, thus reaching full circularity.

From an organizational perspective, we concur with Dery et al. (2017) regarding the positive effect of DTs on data-driven business processes. Hanelt et al. (2021) highlighted in their systematic review that DTs interact with organizational antecedents, especially with organizational and managerial characteristics. Similarly, Dewan et al. (2003) observed the impact of DTs on organizations' processes, values, and culture.

Our findings delve deeper into these topics, suggesting that all the studied DTs yield significant organizational outcomes. These outcomes include fostering an organizational culture centered on sustainability and innovation, implementing HR practices aimed at developing tech skills and competencies, and optimizing the supply chain. These insights lead us to hypothesize that not only blockchain technology – as identified by Khan et al. (2021) – but also all the analyzed DTs play a role in enhancing organizational performance. The influence of each individual DT on organizational performance warrants further exploration through focused research.

6. Conclusion

6.1 Theoretical contribution

The extant managerial literature suffers from a paucity of empirical studies investigating the link between digital technologies and the circular economy (Rosa et al., 2020). This is particularly true with respect to SMEs and circular startups, the latter having attracted increasing attention in recent research (Henry et al., 2020; Prosman & Cagliano, 2022; Von Kolpinski, 2022).

We respond to the call for research advanced by Centobelli et al. (2020), who propose to investigate how Industry 4.0 technologies enable circular economy practices.

Through our exploratory study, we investigate how circular startups employ digital technologies to develop circular practices at both the downstream and upstream levels. Building on the conceptual frameworks developed by Urbinati et al. (2017) and Centobelli et al. (2020), we propose a framework linking digital technologies with the degree of circularity reachable through them. By reading our findings through organizational lenses, we also contribute to the recent literature linking circular practices with DTs through an organizational perspective (Khan & Qianli, 2017; Khan et al., 2021).

The findings of our study suggest that the adoption of DTs requires organizations to look for skilled human resources and proper knowledge to fully benefit from the adopted DTs. We deem that this aspect should be further analyzed, as it might open interesting research avenues.

6.2 Managerial implications

Our findings offer some relevant managerial implications. Our empirical investigation involving circular startups adopting DTs unveils the practical application and potential that such technologies have in allowing circular practices both at the upstream and downstream levels. Through our empirical model, we illustrated which DTs could be implemented to achieve different levels of circularity. We therefore suggest circular entrepreneurs and managers wishing to implement circular practices to draw inspiration from our model to understand which digital technology 4.0 they might leverage to implement the planned circular practices and/or to understand how to reach a full degree of circularity. We also recommend that practitioners evaluate the implications that the chosen DT may have on the workforce (such as needed skills and competences) and estimate the impact that the DT may have on organizational performance.

6.3 Limitations and future avenues for research

The paper presents some limitations. First, the number of cases is limited to five: as expected by the chosen methodology (Yin, 2014), the findings enable analytical generalization but not statistical generalization (ibid). Second, our case studies are limited in terms of size (startups), industries (digital services, textile, additive manufacturing, technologies) and geographical location (Italy). Future research could perform the investigation by including circular firms of different dimensions (medium to large firms) and located in various geographical areas, including developing countries that have been under-investigated thus far. Moreover, it would be useful to perform longitudinal case study research to monitor how digital technologies will be employed over time by startups to enable circular practices both at the upstream and downstream levels and which organizational outcomes stem from their implementation.

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