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# Digital technologies catalyzing business model innovation for circular economy—Multiple case study

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ABSTRACT

Digital technologies have been increasingly argued to enable circular economy business models. However, the extant research is based on conceptual and review studies, leading to a lack of understanding of how digital technologies enable individual firms in real-life settings to improve their resource flows and value creation and capture and thereby enable business model innovation to emerge. In this study, we conducted a multiple case study with interviews and document data from four Northern Europe-based forerunner firms with circular economy business models enabled by digital technologies, providing two key contributions to the extant literature. First, we generate an empirical evidence -based synthesis of improvements of resource flows and value creation and capture in firms' businesses across industries, highlighting the critical role of knowledge generation. Second, we develop a model of four key types of business model innovation for circular economy catalyzed by digital technologies, varying on incremental and radical improvement to both the resource flows and value creation and capture, providing theoretical insights to both business model innovation and digital technologies in circular economy. For managers, we suggest suitable digital technologies for the key types, highlighting the importance of radical business model innovation catalyzed by data integration and analysis technologies.

## 1. Introduction

Innovating new business models that enable firms to create value while adhering to circular economy (CE) principles is a requirement for the systemic adoption of the CE concept (Bocken et al., 2016; Centobelli et al., 2020). This concept poses a large business opportunity that could lead to benefits valued at €1.8 trillion by 2030 in Europe alone (Bressanelli et al., 2018). However, capturing this opportunity requires firms to adopt CE in their business by, for example, moving from linear to circular thinking in supply chains and from product-centric to service-centric value propositions in their customer interfaces (Urbinati et al., 2017). Digital technologies, especially those related to the concept of Industry 4.0 (Nascimento et al., 2018), have been identified as important enablers of CE business models. For example, they allow firms to share data within their supply chains and identify and track products and materials, which improve their ability to retain value (de Sousa Jabbour et al., 2019). However, extant research on the implementation of digital technologies and related business model innovations for establishing CE within firms remains conceptual and lacks empirical evidence, especially on how implementing digital technologies allows firms to develop CE business models (Centobelli et al., 2020; Rajala et al., 2018). Given that the gap between identifying a potential solution and adopting it into the core business of the firm is the main barrier to putting CE business models into use (Geissdoerfer et al., 2018), understanding how firms leverage digital technologies in business model innovation to enable CE is crucial.

The CE has the potential to simultaneously improve the environmental sustainability and economic aspects of a business through the systemic improvement of resource efficiency (Ghisellini et al., 2016). Reflecting this potential, CE research has widely adopted the business model concept (Ferasso et al., 2020; Lüdeke-Freund et al., 2019). A CE business model describes a holistic view of a firm's business, including a value proposition that entices customers to choose a firm over its competitors (Ranta et al., 2020), supports value creation, offers a delivery system that fulfills the value proposition while increasing circularity through a combination of narrowing, slowing, and closing resource flows (Bocken et al., 2016), and implements value capture mechanisms that allow the firm to capture part of the value that is created as profit (Ranta et al., 2018) while adhering to CE principles (Bocken et al., 2016). Thus, while innovating a CE business model, firms need to identify how the business model will improve circularity, value creation, and capture (Frishammar and Parida, 2019;

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**Table 1**
Digital technologies in CE: Extant studies and identified gaps.

| Authors | Topic and study type | Digital technologies in CE | Identified gaps |
|---|---|---|---|
| Pagoropoulos et al. (2017) | Systemic literature review evaluating the application of key digital technologies in CE. | Three architectural layers for digital technologies: data collection (RFID & Internet of Things), data integration (database management systems and product lifecycle management), and data analysis (big data analytics and artificial intelligence). | The role of data integration is minimally discussed in the literature.<br>Economic and business perspectives are currently mostly neglected.<br>The research area is in a pre-paradigmatic stage and thus lacking concrete case studies. |
| de Sousa Jabbour et al. (2018) | Conceptual paper showcasing how Industry 4.0 technologies could enable CE strategies. | Industry 4.0 technologies (cyber-physical systems, cloud manufacturing, Internet of Things, and additive manufacturing) that are suitable for enabling CE business models. | Application of resource-based theory, stakeholder theory, institutional theory, and ecological modernization to research the use of digital technologies in CE business models. |
| Alcayaga et al. (2019) | Integrative literature review synthesizing literature from various domains describing interrelationships among the Internet of Things, product-service systems, and CE and proposing a conceptual framework of smart-circular systems. | Smart use, smart maintenance, smart reuse, smart remanufacturing, and smart recycling enabled by remote monitoring, product lifetime databases, analytics and business intelligence, and actuating capabilities impacting all parts of the business model. | Further empirical research is needed because the covered literature focuses on conceptual, theoretical studies.<br>Antecedents, outcomes, and moderators of business model innovation as related to the smart models. |
| Uçar et al., (2020) | Literature review and three case studies identifying the roles of digital technologies supporting CE. | Digital technologies as both triggers for and enablers of CE business models through data collection, data exchange, data storage, and data analysis functionalities. | Further empirical studies are required to validate the findings.<br>Other industrial sectors should be explored. |
| Rosa et al., (2020) | Systematic literature review assessing the relations between CE and Industry 4.0, including a framework highlighting the links between these two concepts. | Circular Industry 4.0 technologies: additive manufacturing, big data and analytics, cyber-physical systems, Internet of Things, and simulation.<br>Digital CE application areas: digital transformation, lifecycle management, disassembly 4.0, reuse 4.0, recycling 4.0, remanufacturing 4.0, resource efficiency, circular business models and smart services, and supply chain management. | Lacking empirical evidence on how CE and Industry 4.0 principles are applied in practice by companies.<br>How Industry 4.0 technologies impact the design of CE business models. |

Pieroni et al., 2019).

The role of digital technologies in enabling CE business models has recently become a fruitful research agenda (de Sousa Jabbour et al., 2018). Digital technologies from the Industry 4.0 concept that originated in the manufacturing industry (Nascimento et al., 2018) provide capabilities that enable CE business models, such as those that identify and track materials within an industrial supply chain, to implement efficiency improvements within manufacturing processes (Centobelli et al., 2020) and reduce product-service systems' need for product ownership (Alcayaga et al., 2019). Multiple review studies have recently emerged on the role of digital technologies in CE development. As shown in Table 1, these reviews have identified categories of digital technologies that can enable adhering to CE. They are exemplified by the architectural layers of data collection, data integration, and data analysis (Pagoropoulos et al., 2017) and the Industry 4.0 technologies of cyber-physical systems, cloud manufacturing, the Internet of Things, and additive manufacturing (de Sousa Jabbour et al., 2018). These studies have also identified suitable application areas for digital technologies in the CE, such as digital transformation, lifecycle management, disassembly 4.0, reuse 4.0, recycling 4.0, remanufacturing 4.0, resource efficiency, circular business models and smart services, and supply chain management (Rosa et al., 2020). Furthermore application areas specifically in product-service systems, such as smart use, smart maintenance, smart reuse, smart remanufacturing, and smart recycling in product-service systems have been identified (Alcayaga et al., 2019).

While consolidating extant understanding of the research field, these reviews also identify significant gaps in the extant literature. The most significant issue with the current literature is its conceptual nature; it lacks empirical studies corroborating the current literature (Alcayaga et al., 2019; Rosa et al., 2020; Uçar et al., 2020). While few case studies on the subject exist (Chiaroni et al., 2020; Ingemarsdotter et al., 2020; Latilla et al., 2020), those that do tend to focus on single-case firms or industries, reducing the potential for drawing wider implications. Additionally, the reviews identify a need for research on the effect of digital technologies on business model innovation for CE, with Rosa et al. (2020) highlighting the need to address digital technologies' impact on CE business model design, Alcayaga et al. (2019) note the study of antecedents, outcomes, and moderators for business model innovation for CE, and Uçar et al. (2020) identify digital technologies as not only enablers of but also triggers for CE business models. Thus, two major gaps in the current literature on the role of digital technologies as enablers of CE include 1) the lack of empirical research on how the benefits from digital technologies in CE business models are realized in individual firms across industries and 2) how digital technologies act as catalysts for the innovation of new CE business models. To address these gaps, our research objective was to study *how digital technologies enable business model innovation for CE in individual firms across industries.* More specifically, we aimed to answer three research questions on the role of digital technologies in business model innovation for CE: 1) what digital technologies must firms use in their CE business models; 2) how do digital technologies enable firms to improve the circularity of their business; and 3) how do digital technologies catalyze business model innovations for creating and capturing value from the improved circularity?

To answer these research questions, we conducted a multiple-case study in four forerunner firms from diverse industries that had implemented digital technologies into their operations that led to business model innovations for CE. Here, we provide two intended contributions to the fields of digital technologies and business model innovations in CE. We firstly develop an empirical evidence-based synthesis on improvements in resource flows, value creation, and capture that lead to business model innovation for CE. Secondly, we develop a model of four key types of business model innovation for CE that is catalyzed by digital technologies and varies in incremental and radical improvement to the resource flows, value creation, and capture. Data collection technologies enable incremental business model innovations, where revealing inefficiencies in extant business models can lead to value capture through incremental optimizations of processes and supply chains. Data integration and analysis technologies enable radical business model innovation, where opportunities for customer-facing differentiation are revealed, leading to the development of new value propositions and value capture mechanisms from the radical closing of resource flows. These findings also generate practical insights for managers in firms that are moving toward or are already operating CE business models.

## 2. Theoretical background

### 2.1. Circular economy as an emerging setting for business development

The circular economy offers pathways toward more sustainable business through activities that retain the value of materials and products already in circulation for longer, consequently reducing the extraction of raw materials from nature and accumulation of waste in landfills. The CE approach has caught the attention of businesses and policymakers due to its promises of simultaneous environmental and economic benefits in particular (Ghisellini et al., 2016). To achieve the environmental and economic benefits proposed by the CE, much business development is required. Firms must adopt CE principles into their operations and turn their linear models more circular and resource efficient. They must rethink their business models (Ferasso et al., 2020), i.e., the architecture of their value creation, delivery, and capture mechanisms (Teece, 2010).

A central aspect of a CE business model is its contribution towards improving circularity of the business, i.e. how the business model adheres with CE principles. Regarding material flows, CE can be realized through the so-called 3R principles of reduce, reuse, and recycle, derived from the waste management hierarchy (Ghisellini et al., 2016), and the extended versions of up to 9Rs, highlighting diverse reusing potentials (Kirchherr et al., 2017). Another conceptualization offered by Bocken et al. (2016) suggests that CE business models should aim to narrow, slow, or close resource flows. Bocken et al. (2016) proposes *slowing resource flows* by realizing the extension of product life through product lifecycle-extending design and services, such as repairing and remanufacturing; *closing resource flows* by preventing end-of-life products and materials from becoming waste and redirecting them as feedstock for production; and *narrowing resource flows* by reducing the resources used to make each product. Through these three resource flow strategies, the same or increased value can be created through the drastically reduced use of natural resources and generation of waste. The slowing strategy allows a single product to retain its value longer, the closing strategy allows valuable products to be produced from materials already in circulation, and the narrowing strategy reduces the number of resources needed to produce the same value.

Thus far, extant research has acknowledged digital technologies as important enablers of improved circulation that are crucial to the operation of CE business models, particularly in the above-discussed resource flow focused perspective (e.g., Centobelli et al., 2020; de Sousa Jabbour et al., 2019). However, there is a lack of understanding of how digital technologies contribute to the innovation of CE business models by capturing value from resource flow improvements. Even though previous conceptual and review studies (see e.g. Centobelli et al., 2020; de Sousa Jabbour et al., 2018; Pagoropoulos et al., 2017) have provided some initial understanding, we lack an understanding of how firms use digital tools in real-life settings to improve their material flow and value capture through business model innovation for CE (Alcayaga et al., 2019; Rosa et al., 2020).

### 2.2. Business model innovation in CE

The research stream on business model innovation for CE has quickly emerged to address the need for firms to rethink their business models (Pieroni et al., 2019). Business model innovation for CE builds on two distinct but overlapping research streams: research on traditional business model innovation (Foss and Saebi, 2016) and the maturing research stream of sustainable business model innovation (Geissdoerfer et al., 2018; Lüdeke-Freund et al., 2018). While the intensity of a business model innovation can differ based on novelty (i.e., whether the business model is new to the firm or the industry) or degree (i.e., whether it is incremental and only individual parts change or is radical and thus the entire architecture of the business model changes), a defining factor for business model innovation is that parts of the business model of the firm change (Foss and Saebi, 2016). This leaves the business model innovation concept open to interpretation, which allows further research in different, more specific fields, such as the CE (Pieroni et al., 2019) to attach to.

Business model innovation for CE adds stronger goal orientation to the traditional business model innovation perspective. While the objective of business model innovation is generally to improve a firm's ability to seize opportunities or neutralize threats in its environment with the resources that it has (Teece, 2018), innovating a CE business model necessitates that the outcome is an improvement based on CE principles. The resource flow strategies of slowing, narrowing, and closing resource flows (Bocken et al., 2016) provide direction as to what is required to improve CE in a business model innovation, but they do not consider the main purpose of the business model: creating, delivering, and capturing value (Teece, 2010).

To combine the value perspective with the implementation of CE principles, three distinct streams of circular business model literature can be identified, each with their own approach to business model innovation for and the role of digital technologies in CE. The streams, along with key sources from each stream, are displayed in Table 2. The most prominent of these streams is the strategies, patterns, and components approach, which identifies alternative methods for implementing a CE in a business model (Lewandowski, 2016; Lüdeke-Freund et al., 2019). This perspective focuses on enabling business model innovation for CE within firms by identifying and showcasing business model strategies, patterns, and components that have been shown to improve circularity and value creation, usually following a distinction of a value proposition, value creation and delivery system, and value capture, as central components of a business model (Ranta et al., 2018). Through a systematic review of extant research on this stream of research, Lüdeke-Freund et al. (2019) identify six major

**Table 2**
CE business model (CEBM streams and the role of Business Model Innovation (BMI) and digital technologies.

| CEBM Stream | Perspective to BMI | Role of Digital Technologies | Key Sources |
|---|---|---|---|
| *Strategies, patterns, and components* | Firms innovate their business models for CE by identifying and implementing suitable BM strategies, patterns, and components. | Digital technologies as tools to improve the performance of CEBM strategies, patterns, and components. | Bocken et al. (2016); Lewandowski (2016); Lüdeke-Freund et al. (2019); Ranta et al. (2018) |
| *Managerial practices* | Business model innovation for CE requires specific managerial practices, which constitute the implementation and adoption of a business model for CE. | Digital technologies support the implementation of managerial practices for CE transition in firms. | Centobelli et al. (2020); Ünal et al. (2019); Urbinati et al. (2020, 2017) |
| *Product-service systems* | Firms that innovate their business models by adding services to their product offerings or selling their products as services can simultaneously improve the circularity of their business. | Digital technologies as central enablers of implementing product-service systems (e.g., product tracking and product lifecycle information leading to improved ability to close resource flows). | Alcayaga et al. (2019); Stahel (2010); Tukker (2015) |

CE business model patterns that link value creation to the resource flow strategies with a full set of identified business model components (Richardson, 2008): repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing, and organic feedstock. Each of the major business model patterns enables value creation for a CE resource flow strategy (Bocken et al., 2016). Repair and maintenance, reuse and redistribution, and refurbishment and remanufacturing create value by slowing resource flows, while recycling, cascading and repurposing, and organic feedstock create value by closing resource flows. Narrowing resource flows was not identified as specific to a CE business model type; therefore, this strategy can contribute to value creation in CE business models widely in this typology (Lüdeke-Freund et al., 2019). However, this stream acknowledges that business models are highly contextual and thus cannot simply be picked from a collection of examples and implemented by a firm (Lüdeke-Freund et al., 2018). Thus, business model innovation requires the firm to identify, design, and implement CE business models that are specifically suitable for their purposes (Frishammar and Parida, 2019; Geissdoerfer et al., 2018).

The literature stream of managerial practices for CE business models takes a more nuanced view of the internals of a firm implementing CE. From the perspective of a single firm, business model innovation for CE requires a firm to, for example, manage its value chains in a way that improves the circularity of the firm's resource usage while contributing positively to value creation (Urbinati et al., 2020). Rearrangements can take place in either the downstream value chain (e.g., innovating the customer interface with new types of value propositions and value capture mechanisms geared toward the customer) or the upstream value chain (e.g., innovating the design of the supply chain, moving from a linear to a more circular supply chain) (Urbinati et al., 2017). Managerial practices for value creation and capture from CE are important to realizing these rearrangements because product and service design practices for CE are necessary for capturing value in a CE business model (Centobelli et al., 2020). Overall, in this perspective, business model innovation for CE requires the ability to manage the innovation process and the renewal of the way a firm does business such that it improves their value creation capability within its context (Pieroni et al., 2019). Thus, this stream deepens the strategies, patterns, and components stream from a business model innovation perspective by identifying how the contextual identification and implementation of a suitable business model can be managed (Ünal et al., 2019).

The third stream of literature on business models for CE focuses specifically on the product-service system concepts' ability to both improve value creation and enable improvements in circularity. When adopting a product-service system business model, firms enhance their product offerings with services, ranging from offering maintenance contracts to selling the product as a service entirely (Tukker, 2015). This is argued to improve value creation by moving the focus from providing the product towards providing the performance that the customer expects from the product (Stahel, 2010). Simultaneously, the supporting services can lengthen the lifecycles of products and thus lengthen resource flows and improve take-back and reuse, remanufacturing, and recycling of the product by enabling a continuous relationship between the customer and the supplier firm (Tukker, 2015). In this stream, the focus of business model innovation is on service innovation, and the application of services is seen as an effective pathway toward value creation and improvement in circularity (Hansen and Alcayaga, 2017).

Each of these streams also has a distinctive perspective on how digital technologies support CE. The strategies, patterns, and components approach, while otherwise prevalent in CE business research, has the lowest focus on digital technologies of the three streams. In this stream, digital technologies have been shown to enable certain business model components, such as take-back systems (Lewandowski, 2016), but digital technologies are primarily viewed as novel technologies that need to be innovated in parallel to business model innovation for CE (Lüdeke-Freund et al., 2019). The managerial practices stream takes a deeper consideration of digital technologies, identifying them as important enablers of managerial practices for the implementation of CE. For example, Centobelli et al. (2020) identify technologies like the Internet of Things and cyber-physical systems as enablers of cross-dimensional practices for CE implementation by enabling monitoring, analysis, and control of products' data. In the product-service system stream, digital technologies play a key role in enabling the innovation of new services and the transformation from selling products to selling products as services by allowing the firm to improve its control of the products in circulation (Hansen and Alcayaga, 2017). Specifically, this stream has proposed smart models that, within a product-service system, that enable more effective use and loop closing of products through leveraging product data during the product usage phase as well as during reuse, maintenance, remanufacturing, and recycling activities (Alcayaga et al., 2019).

### 2.3. Digital technologies in CE

In addition to enabling circular economy business models, digital technologies can also act as triggers for innovating new business models for CE (Uçar et al., 2020). Recent research on the CE suggests that the development of emerging digital technologies is driving a shift toward CE practices and innovation (Gligoric et al., 2019; Hansen and Alcayaga, 2017; Stock et al., 2018). Furthermore, a simultaneous transformation toward the implementation of digital technologies in industrial businesses is ongoing alongside the emergence of CE (Kiel et al., 2017a). In industrial businesses, digital technologies are considered to be part of the fourth industrial revolution, called Industry 4.0 or the Industrial Internet (Lieder and Rashid, 2016). These terms refer to the industrial transformation in which data gathering and storing transforms products into value-creating systems (Rajala et al., 2018) that form connected networks of people, products, and systems (Kang et al., 2016). In terms of the digital technologies applied in Industry 4.0, Pagaropoulos et al. (2017) categorize these technologies into three categories based on function: *data collection, data integration, and data analysis*. Data collection technologies include sensors (e.g., radio frequency identification [RFID]) and devices that connect products and users to the Internet (e.g., the Internet of things [IoT]). Data integration technologies store and format data and enable the use of data analysis technologies, which produce and develop information (Pagoropoulos et al., 2017).

Technologies have been similarly categorized by digitalization capabilities: intelligence capability, connective capability, and analytical capability. Intelligence capability refers to upgrading key hardware with digital components that gather data. Connective capabilities refer to linking products wirelessly to one another and the Internet. Analytical capabilities perform knowledge development functions, generating intelligence from the abundant data provided by the sensors and systems (Lenka et al., 2017). Data collection technologies involve RFID, IoT, and cyber-physical systems (CPS) (e.g., Gligoric, 2019). Among data integration technologies, cloud and blockchain technologies are the most frequently discussed (Ardolino et al., 2018). Big data analytics and artificial intelligence (AI) also emerge from the literature as key data analysis technologies (Soroka et al., 2017).

Extant literature regarding the relation of these technologies in CE business models has mostly focused on conceptualizing how digital technologies enable the slowing, narrowing, and closing of resource flows within CE business models. For example, de Sousa Jabbour et al. (2019) mapped digital technologies from the Industry 4.0 literature—more specifically IoT and cyber-physical systems—to different patterns of CE business models. They analyzed there was an effect on designing longer-lasting products, producing products more effectively, or creating reverse logistics, closely resembling the slowing, narrowing, and closing resource flows strategies (Bocken et al., 2016). They found that IoT technologies were widely relevant throughout the three

**Table 3**
The case and data sources.

| *Firm* | *Firm size (Revenue)* | *Industry* | *Main ways in which business models and digitality are used by the CE business* | *Primary and secondary data* |
|---|---|---|---|---|
| Company Alpha | 5300 MEUR | Tools/construction | Provides technologically leading tool products, systems, software, and services for professional construction sites.<br>Provides information on resource efficiency through software applied to products. | Interviews:<br>Services & software Area sales manager 7/2019<br>Secondary data |
| Company Beta | 610 MEUR | Machinery | Provides forest machinery and innovative harvesting solutions based on sustainable development.<br>Uses a buyback-and-replace system to extend the lifecycle of its products. | Interviews:<br>Spare parts manager 7/2019;<br>HSE Manager 7/2019<br>Secondary data |
| Company Gamma | 370 MEUR | Waste management (public) | A municipal body.<br>Provides waste management and water services.<br>Provides a resource-efficient reuse process for city waste. | Interviews:<br>Logistics manager 9/2019;<br>Landfill field manager 7/2019,<br>Project manager 7/2019<br>Secondary data |
| Company Delta | 14,900 MEUR | Oil refinery and technology developer | Produces, refines, and markets oil products and provides engineering services and licensing production technologies.<br>Applies tailored digital solutions to close flows. | Interviews<br>Chief information officer 8/2019<br>Head of Digital Transformation 8/2019<br>Secondary data |

strategies.

Furthermore, reviewing extant literature on digital technologies, Centobelli et al. (2020) described Industry 4.0, IoT, additive manufacturing, cyber-physical systems, and cloud technologies as having a role in designing business models for CE. They demonstrated how the IoT could enable CE through improved monitoring, analysis, and control of products data to extend the lifecycle of products and enable a take-back in the supply chain. They also showed how cyber-physical systems support the optimization of production and maintenance by making data available for decision-making in real-time. Although similar to de Sousa Jabbour et al. (2019), these results reflect how digital technologies from Industry 4.0 allow business models to operate more effectively in relation to the resource flow strategies, without detailing how these might contribute to the creation and capture of value. Research within the context of Industry 4.0 has identified how digital technologies improve competitiveness based on innovative offerings; improve finances through enhanced value creation and cost reductions; improve equipment effectiveness through the optimization of machinery and novel business models, such as hybrid product–service solutions and pay-per-usage models; and improve resource efficiency through the optimization of resource utilization (Kiel et al., 2017b). Supporting this perspective that digital technologies also support value creation and capture in addition to enabling resource flow strategies, Rajput and Singh (2019) found that implementing circular economic principles in the business model of a firm is a major driver of value creation from Industry 4.0 technologies.

To summarize, based on the literature on digital technologies and business model innovation for CE we select two theory-based frameworks for the case analysis. First, to categorize digital technologies already implemented as CE solutions by organizations, we classified digital technologies related to data collection, integration, and analysis (Pagoropoulos et al., 2017). To catalyze the CE, digital technologies must enable value creation and capture based on the systemic efficiency improvements to the resource flows within the economy through business model innovations. Thus, the three resource flow strategies of CE—i.e. slowing, closing, and narrowing resource flows (Bocken et al., 2016)—provide a framework for mapping how the identified digital technologies catalyze CE. Next, we examined empirically how the digital technologies contributed to business model innovations intended to create and capture value from the resource flow strategies using this framework. In the following sections, we explain our methods and then discuss our findings.

## 3. Methodology

### 3.1. Research design and case selection

As the digital technology research field is just emerging (particular in regards to the advancement of CE business models), we chose a qualitative multiple case study strategy to examine and develop a theoretical understanding of the focal phenomenon in its natural setting (cf. Yin, 1994) by integrating the existing research knowledge and new empirical insights derived from the cases analyzed in the present study (Dubois and Gadde, 2002). By selecting a multiple case study strategy, we were able to analyze distinctive, individual company cases in detail, regarding how digitalization has catalyzed their business model innovation, and synthesize similar patterns identified across different company cases.

The case selection was purposive and sequential and followed the principles of *theoretical sampling* (Eisenhardt, 1989) and several selection criteria. 1) Using maximum variation criteria (Patton, 1990), we selected cases from different industries and businesses, including different operators (from both the private and public sector), business model patterns (both material and product-focused), and company sizes, as we expected these aspects to uncover contrasting patterns and variation in how companies captured the value that digitalization for CE brought to business models (cf. Eisenhardt and Graebner, 2007). 2). By choosing cases where the diverse resource flow strategies and CE principles, including narrowing, slowing, and closing resource flows are followed and enabled by digital technologies, we ensured that our findings captured the full spectrum of CE business and originating business model innovations. 3) By selecting successful cases (Patton, 1990) and focusing on forerunner organizations and companies that already ran mature, profitable businesses, we were able to analyze realized, implemented digitalization for CE and related business model innovations. Additionally, to improve case selection, we conducted a preliminary analysis of more than 10 cases based on the above-mentioned criteria and conducted preliminary interviews with experts to ensure that the case selection was optimal. As a result, the following four cases (see Table 3) from different industries, headquartered in Northern Europe while mostly conducting business globally, were selected for examination.

### 3.2. Data collection and analysis

The primary and secondary data sources of our case study are displayed in Table 1. The primary dataset comprised semi-structured face-to-face interviews, conducted in July–September 2019 with key actors, such as managers and experts who were directly involved in the use of digitalization and business development in the field of CE. We interviewed several respondents for each case. The interviews typically lasted 90 minutes and were recorded and transcribed. Field memos were written during the interviews. In all cases, interview data were substantiated by the secondary dataset that comprised internal and media-originated data, such as technical documents, articles, and firms' websites and other web pages concerning the solutions, the companies, and their evolving market and business environments.

The primary and secondary datasets addressed the following themes: 1) what digital solutions were used and how they improved CE principles; 2) what resource flow strategies were adopted and what were the resulting economic value-creating benefits (i.e., how the digital technologies enabled CE improvement while improving value creation and capture from business opportunities), 3) what opportunities and barriers emerged when digital solutions were implemented for CE in the company's business process, on both a company- and larger-system level; and 4) what successes and failures related to business models and business model innovations emerged, originating from the application of digital technologies for the CE.

In the analysis phase, we started with a within-case analysis by providing an overview on how digital technologies enabled CE principles in each case and consequently mapping the relationships between the application of digital technologies for the CE in each company and their business model innovation process (Section 4.1). We then moved to a cross-case analysis (Section 4.2), where we compared cases and thus synthesized more general patterns and identified similarities and differences across the cases. Multiple tools and tactics enhanced our analysis: we followed a coding procedure based on a theoretical framework in the analysis of interviews, assisted by software. We drew case-specific illustrations and organized aspects of the framework in multiple tables. We then compared these and applied researcher triangulation to ensure the trustworthiness of the results (Flick, 2004).

## 4. Results on digital catalysts of CE

The results of this study are reported in two parts. First, the results from individual cases about which digital technologies the firms had implemented and how the technologies enabled business model innovation for circular economy to create and capture value from the circular economy resource flow strategies are described. Second, the results are summarized through a comparative case analysis, identifying similarities and differences between the findings from individual cases.

### 4.1. Case results

#### 4.1.1. Company Alpha

Company Alpha provides tools for the construction industry, mostly through rental and service contracts. The digital technologies that company Alpha has implemented are primarily *data collection technologies*. The company leverages *IoT technologies* to gather data, such as location and maintenance status from the tools. It delivers the data to customers and the firm itself through *cloud technologies*, using web and mobile interfaces for customers. In addition to the cloud technology--facilitated access, tool data can be accessed and updated through RFID tags combined with the IoT sensors on the tools, enabling convenient access to, for example, instructional information and maintenance services for a specific tool. The company uses cloud technologies primarily as a way to display collected tool data. It has not yet implemented data integration or data analysis technologies that would allow it to acquire more in-depth insights.

The ability to track the connected tools through IoT technologies enables customers to use tools and the company's own service-based solutions more efficiently by drastically shortening the lead time for identifying the availability of tools and reducing warehousing needs. Consequently, a smaller fleet of tools is needed to fulfill the needs of a larger customer base, leading to *narrower resource flows*. By providing streamlined access to maintenance services, the combination of IoT and cloud technologies allows customers to maintain their tools in better condition, reducing premature breakdowns of the tools, thus *slowing resource flows*. The digital technologies allow the firm to create and capture value better from the CE resource flow strategies through multiple methods, in both the upstream and downstream sides of the business model. From the upstream side, the ability to fulfill the needs of a larger customer base with a smaller overall fleet of tools and the ability to access health and maintenance history information for a specific tool while maintaining the tool fleet improves the cost efficiency and service quality of the firm's business model.

The convenient access to tracking, maintenance, and instructional information for the tools greatly increases the value of the tools for service contract customers and the desirability of maintenance services for other customers. This leads to a positive impact on the company's revenue, improving the business model from the downstream side with novel value propositions. Overall, in company Alpha, digital technologies enable incremental improvements to CE, as resource flows narrow and slow while catalyzing radical improvements to value creation and capture through the business model with both cost reductions and revenue increases.

#### 4.1.2. Company Beta

Company Beta manufacturers and sells wood harvesting machinery for the forest industry. The company has implemented *data collection* and *data integration* technologies to support its business. *IoT technologies* are used to collect health and usage data from the harvesting machines, accessible by both the company and the customer who owns the machine. As the machinery is often used in remote locations, the data can be stored on the machine and updated via a central system when a network connection is available. To integrate data, an *ERP system* is used, facilitating the integration of machine data for use in maintenance operations and product development. Further, a customer-facing *online ordering system* has been implemented to facilitate customer orders for remanufactured spare parts and components.

Data from the machine usage is used in product development to optimize the fuel efficiency of the machines, narrowing resource flows, and to improve the durability of the machines, preventing premature breakdowns and thus slowing resource flows. Furthermore, machine data is used in maintenance operations, also slowing resource flows. Both the tracking of the machine health and the online ordering system for spare parts enable the closure of resource flows, as potentially reusable parts from maintained machines can be more efficiently extracted for remanufacturing and sold directly to customers or used in maintenance operations as spare parts or components.

Both upstream and downstream improvements are realized in the business model of the company. Upstream, the use of data in product development increases knowledge about how customers use the machines and allows the firm to make machines more durable and cost-effective to use, and thus more desirable for the customer. The fuel consumption improvements are impactful, as the majority of the running costs of heavy-duty machinery are fuel costs. Furthermore, the use of data in maintenance operations allows the firm to improve both the quality and cost-efficiency of its maintenance services, while allowing it to capture parts for remanufacturing and further resale.

Downstream, the convenient online ordering system increases the demand for remanufactured spare parts directly from the company, contributing to revenue improvements. In fact, the combination of being able to track the location and health of machines and collect usage information has improved the ability of the company to provide timely maintenance services. The ability to remanufacture and effectively sell spare parts originating from the maintenance services has

**Table 4**
Identified digital technologies and how they catalyze business model innovation for the circular economy.

| Case | Identified digital technologies and how they capture value | How catalyzes CE business models | Degree of catalyzed business model innovation |
|---|---|---|---|
| **Alpha**<br>*Product–service system operator,*<br>*Tool manufacturer for the construction industry* | Digital technologies are used for **data collection** and **data integration**:<br>•→The **IoT** collects data from machines, providing machine health and location information.<br>•→**Cloud** technologies integrate and show data to the company and consumer, enabling the potential for offering context-specific maintenance services. | **IoT** technology enables tool tracking, which allows the firm to fulfill the needs of customers with fewer overall tools, narrowing resource flows, and use knowledge from machine data in maintenance to provide higher quality service at a lower cost while slowing resource flows.<br><br>**Cloud** technologies provide customers convenient, timely access to maintenance services, increasing demand for services while slowing resource flows. | **Incremental** improvements to the circular economy, *narrowing and slowing resource flows* through an improved tool fleet, management efficiency, and maintenance services.<br><br>**Radical** improvements to value creation and capture with business model innovation, including cost reductions in existing rental processes and revenue increases through novel value propositions in online accessible maintenance services. |
| **Beta**<br>*Product–service system operator,*<br>*Forestry machine manufacturer.* | Digital technologies are used for **data collection** and **data integration**:<br>•→**IoT** technologies collect machine health and usage data.<br>•→An **ERP system** integrates data for maintenance and product development operations.<br>•→**Online ordering system** allows customers to directly order spare parts inventory. | **IoT** technologies enable the use of machine data in product development, generating knowledge with which the machine's fuel consumption can be optimized to narrow resource flows while making the product more desirable and cost-effective for the customer.<br>The **ERP system** allows maintenance and product development operations to access to knowledge about machine health and customer's machine usage, enabling the provision of higher quality and more cost-effective maintenance services that slow resource flows, and designing products to be more durable, and thus more valuable, to customers.<br><br>The **online ordering system** makes it convenient for customers to order remanufactured parts, increasing direct customer orders, and the closing resource flow of components. | **Radical** improvements to the circular economy, *narrowing, slowing, and closing resource flows* through improved product design, maintenance, and remanufacturing capabilities.<br><br>**Radical** improvements to value creation and capture with business model innovation, including cost reductions in existing maintenance processes and revenue increases through novel value propositions in remanufacturing and service offerings. |
| **Gamma**<br>*Material processor,*<br>*Municipality-owned waste and water management group* | Digital technologies are used for **data collection**:<br>•→**IoT** technologies collect data from logistics vehicles. | **IoT** technologies enable tracking of the logistics system, increasing knowledge about how it functions, and allowing identification of opportunities for cost reductions, leading to narrower resource flows. | **Incremental** improvements to the circular economy, *narrowing resource flows* through improved management of logistics.<br>**Incremental** improvements to value creation and capture with business model innovation, including cost reductions in the logistics system. |
| **Delta**<br>*Material processor,*<br>*Producer of refined products from renewable feedstock in the oil industry* | Digital technologies are used for **data collection, data integration,** and **data analysis:**<br>•→**IoT** technologies collect data from chemical processes and the supply chain.<br>•→**Cloud** technologies store, integrate, and analyze large volumes of data.<br>•→**AI** technologies provide forecasting capabilities. | **IoT** technologies enable the optimization of chemical processes and supply chains, enabling production with fewer optimally selected renewable raw materials and reducing costs while improving the quality of the product and narrowing and closing resource flows.<br>**Cloud** technologies allow the company to access larger volumes of data from the supply chain, increasing knowledge about its real-time operation, thus enabling a cost-effective, more reliable supply chain while narrowing and closing resource flows in new ways.<br>**AI** technologies allow the company to better forecast supply for waste materials and demand for refined products, developing knowledge for supply chain management and reducing unnecessary warehousing and potential shortages, thus reducing costs and increasing revenues, while closing resource flows. | **Radical** improvements to circular economy, *narrowing and closing resource flows* through improved resource efficiency in chemical processes and shifting to waste streams as raw materials for production.<br>**Radical** improvements to value creation and capture with business model innovation, including both cost reductions in chemical processes and the supply chain and revenue increases through shifting from non-renewable raw materials to waste streams for production. |

improved the value capture potential from services drastically. The firm has recently moved toward securing service contracts with its customers, rather than focusing on just selling high-quality machinery. Overall, in company Beta, digital technologies enable radical improvements to both the CE perspective, enabling the closure of resource flows, and value creation and capture through the business model with both cost reductions and revenue increases.

#### *4.1.3. Company Gamma*

Company Gamma manages waste and water services in one of Finland's largest metropolitan areas, serving more than a million residents. The company has only implemented data collection technologies to track the logistics of its waste management system. IoT technologies and digital tags automatically identify and store data on waste collection trucks when they, for example, enter waste management facilities. The company does not collect data to track materials within its waste processing system, as this would involve placing sensors in collection bins; as the company has approximately 200,000 units, this cost would have exceeded the benefits.

With the use of data collected from the logistics system, the company is able to optimize the logistics of its waste management, reducing fuel consumption and the vehicle fleet needed in the logistics system. Thus, digital technologies enable the narrowing of resource flows. From the perspective of value capture from CE resource flow strategies, the effect of digital technologies on the business model is, therefore, a reduction in costs for the logistics operations (i.e., upstream of the business model). Also, as the resulting change in the business model is the optimization of the existing business model without new components or changes to its architecture, the business model innovation catalyzed by the digital technologies is incremental. Thus, the overall effect of digital technologies in CE on value creation and capture is incremental.

#### 4.1.4. Company Delta

Company Delta operates globally in the oil industry and is a forerunner in refining products from renewable sources. It uses digital technologies for data collection, integration, and analysis. The company uses IoT technologies in its internal processes and in its supply chain to collect data from material flows. It uses cloud technologies to integrate and analyze large volumes of data originating from its IoT systems. In data analysis, AI technologies, such as machine learning, are especially important for the company, as they allow insights to be drawn effectively from the big data the company accumulates.

The combination of digital technologies used within the processes and the supply chain of the company optimizes production processes, narrowing resource flows. Furthermore, as the company can use multiple renewable raw materials for its products, forecasting capability provided by AI and cloud technologies enable the firm to accommodate its production processes for the specific renewable raw material available, thus improving its ability to replace non-renewable raw materials while closing resource flows.

From the perspective of business model improvements enabled by these digital technologies, the effects on company Delta's business model are mostly upstream. The digital technologies enable optimizations in the chemical processes of the firm, simultaneously improving the quality of the product and reducing costs. Furthermore, the analytical capabilities in the supply chain enable forecasting the supply of renewable raw materials and demand for refined products. This helps improve the cost-effectiveness of the supply chain and reduce potential shortages, thus reducing costs and potentially improving revenue for the company. As the renewable raw materials are often sources like biowaste, the suppliers for the firm drastically change. The value capture mechanisms of the business changes, as the company can receive revenue by refining biowaste. Overall, in company Delta, digital technologies enable radical improvements to both the CE perspective, enabling the closure of resource flows, and value creation and capture through the business model with both cost reductions and revenue increases.

### 4.2. Comparison of the cases

In each of the cases, digital technology had an effect on business model innovation, creating business value from improvements in CE resource flow strategies. Table 4 summarizes the results from each case.

Of the digital technologies identified, data collection technologies are present in each of the cases. The ability to collect data is a necessity before it can be integrated and analyzed. Thus, the presence of data collection is not entirely surprising. IoT technologies are the most common data collection technology, indicating the need for connectivity and data availability in CE solutions. In data integration, identified in the Alpha, Beta, and Delta cases, both cloud technologies and ERP systems were identified as potential solutions, both being able to facilitate connection of data collected through the IoT technologies to other data sources. Data analysis technologies were identified only in company Delta, where AI technologies were used to provide forecasting capabilities in the supply chain, for example.

From the perspective of CE, resource flows were narrowed with the digital technologies in each of the cases through optimizations to the firm processes using different tracking capabilities. Resource flows were slowed in the Alpha and Beta cases, where the companies provide products to customers. The digital capability for slowing resource flows was the ability to provide both timely and high-quality maintenance services with the support of machine health and usage data.

Resource flows were closed in the cases of company Beta and Delta using different digital capabilities. In company Beta, the improved maintenance service capability was used to gain access to parts with the potential for remanufacturing and, paired with an online interface where customers could directly order the remanufactured spare parts, created an effective closed-loop system for parts and components of the machinery. In company Delta, the ability to forecast supply for different waste streams as renewable raw material for the company's processes allowed it to substitute them for non-renewable raw material, thus closing resource flows.

In terms of the degree of the business model innovation catalyzed by the digital technologies, the effect on the business model of Gamma was incremental optimization and improvement to the already existing business model, without the introduction of drastic novelties. In company Alpha, Beta, and Delta, the business models changed more radically. Company Alpha has been able to improve the value proposition for its maintenance services drastically while improving the efficiency of the rental services of its tools. Company Beta has shifted from a mainly product-oriented business model to a combination of products and service, due to the increased capability to provide timely, even predictive maintenance, and capture parts for remanufacturing through service contracts. Company Delta has drastically changed the composition of its supply chain from a linear, non-renewable raw material–based system to a dynamic, analytics-enabled supply chain, consisting of multiple sources of renewable raw material, where it can potentially capture revenue by sourcing the raw materials of its processes by taking in biowaste.

## 5. Discussion and conclusions

### 5.1. Discussing results in light of the theory

Fig. 1 synthesizes general patterns from our diverse cases from different industries regarding the improvements through which digital technologies catalyze value creation and capture in circular economy. We found that the improvements consisted of digital technologies enabling companies to optimize and improve their own processes, for example, through inventory management and efficient material processing. Additionally, digital technologies enabled companies to innovate supplier and customer interfaces, for example, through increased customer knowledge and material tracking.

These findings support earlier conceptual literature about digital technologies in CE, such as the usefulness of intelligent-goods for product tracking in the implementation of product-service system type business models (Alcayaga et al., 2019), and big data capabilities for improvement of CE operations (de Sousa Jabbour et al., 2019). Digital technologies were also linked to the upstream and downstream taxonomy of Urbinati et al. (2017) by showcasing empirical evidence of improvements facilitated by digital technologies in both directions of the value chain.

The importance of accumulation of knowledge is highlighted in our cases as the enabling factor for improved operations and new business model innovations. For example, improved customer knowledge led to the identification of novel value creation opportunities in company Beta. This refinement of data to knowledge has been lacking in previous research that has identified the benefits of digital technologies for CE (see, e.g., de Sousa Jabbour et al., 2019; Rajput and Singh, 2019), and improves understanding of how digital technologies can trigger business model innovation for CE (Uçar et al., 2020). Understanding the role of knowledge generation also builds on the managerial practices required for CE business models, highlighting that, in order to benefit from digital technologies, managers need to identify how to accrue new knowledge that allows business model improvements (Centobelli et al., 2020).

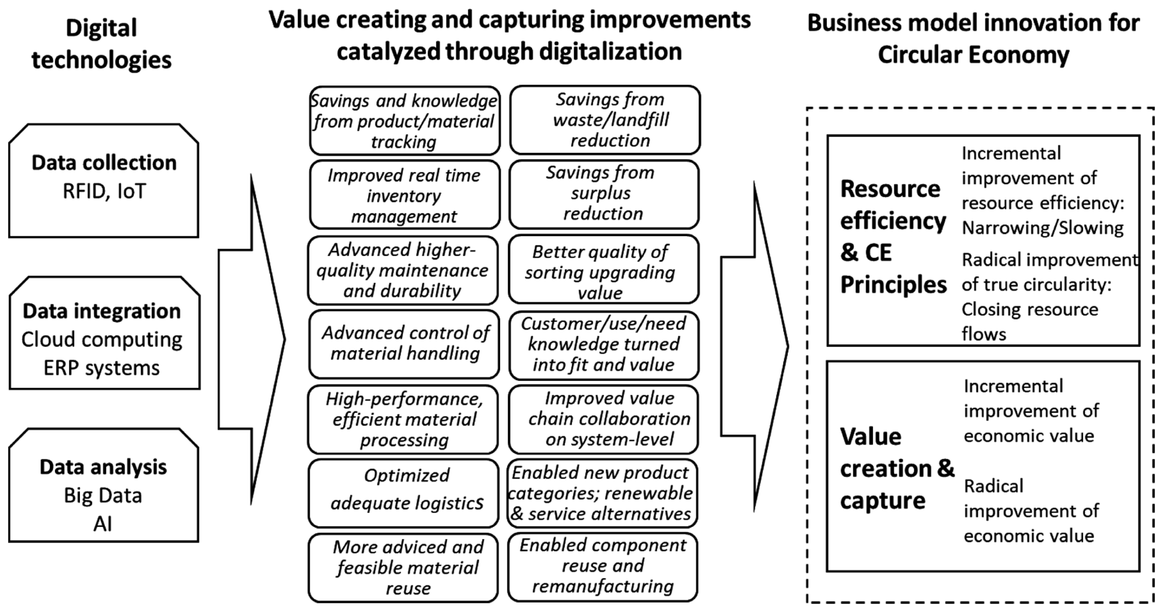


**Fig. 1.** Synthesis on how digital technologies catalyze business model innovation for CE through value creation and capture and resource efficiency and CE principle improvements across industries.

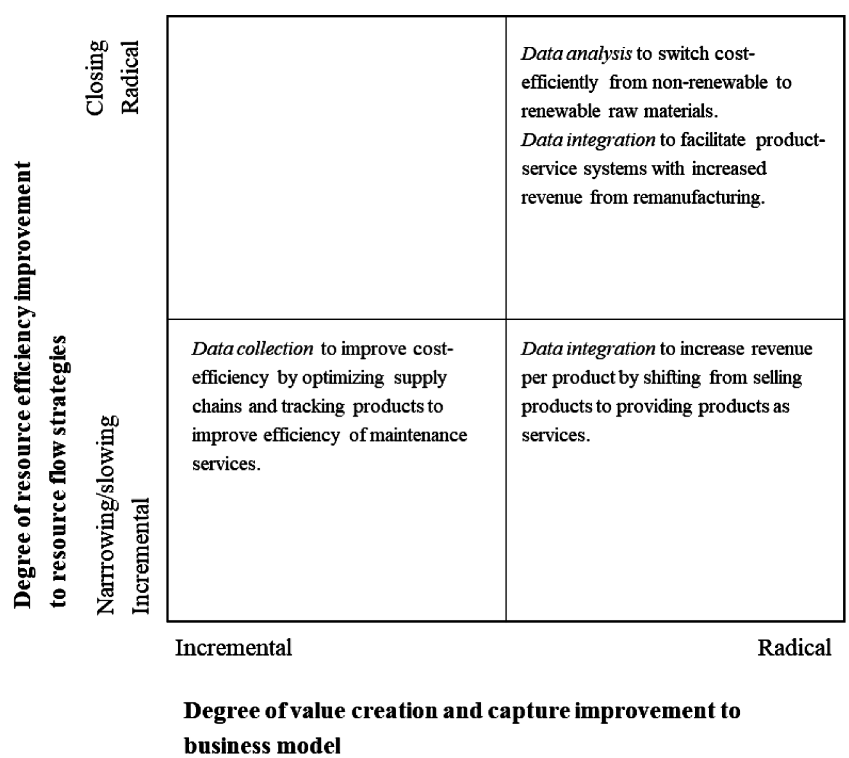


**Fig. 2.** Model of four key types of business model innovation for circular economy catalyzed by digital technologies. .

Our findings showcase the connection between the degree of value creation and capture improvements and the extent of resource flow strategy improvement, and the ability of different types of digital technologies to facilitate such business model innovations for CE. We identify that business model innovations for CE consist of four types of configurations, displayed in the conceptual model in Fig. 2. Business model innovations for CE vary according to their extent of improvement of resource flow strategies, which can be incremental (narrowing or slowing resource flows) or radical (closing resource flows) (Bocken et al., 2016), and according to the degree of business model innovation, which can be also be incremental (improvements to the existing business model) or radical (novel improvements to value creation and capture) (Foss and Saebi, 2016).

Mapped to these types, company Gamma represents an incremental-incremental case, company Alpha an incremental-radical case, and companies Beta and Delta radical-radical cases. Of our diverse cases, we did not identify any in which incremental innovation of the business model would enable radical improvement to the CE. These findings build on the CE business model patterns of Lüdeke-Freund et al. (2019) by identifying the need for radical changes in value creation and capture of companies in order to enable radical closing of resource flows, whether the companies are originally product or material focused.

Furthermore, based on our results, data collection capabilities alone catalyze only incremental business model innovations in which value capture from the narrowing or slowing of resource flows is enabled, as in company Gamma. As for the advancement of CE, closing resource flows is necessary (Lüdeke-Freund et al., 2019); in this respect, our results highlight the importance of data integration and data analysis technologies. Thus, the findings showcase the ability of different types of technologies to catalyze business model innovations for CE, building on the identification of data collection, integration and analysis technology types by Pagoropoulos et al. (2017) and enabling further analysis of their usefulness when implemented by firms from both CE and value creation perspectives.

### 5.2. Theoretical implications

Our study proposes two contributions to the fields of digital technologies in CE and business model innovation for circular economy. First, contributing to the so-far conceptual research in the field of digital technologies in CE (Alcayaga et al., 2019; Rosa et al., 2020; Uçar et al., 2020), we provided an empirical evidence -based synthesis of improvements of resource flows and value creation and capture in firms' businesses across diverse industries. Our findings primarily support the earlier conceptual literature, especially in showing how firms employ digital technologies to improve their operations (de Sousa Jabbour et al., 2019) in diverse application areas for CE (Rosa et al., 2020). The extensive set of novel digital technology–enabled improvements identified and validated in this study clarify the critical role of knowledge generation as a managerial practice (Centobelli et al., 2020), and rationalizes practices that are important in both the supply chain and customer interfaces of the business model (Urbinati et al., 2017).

Second, we built a model for business model innovation for CE catalyzed by digital technologies. By identifying four key types of business model innovation for CE, varying on incremental and radical improvements to resource efficiency and value creation and capture, we contribute to the emerging business model innovation for CE literature. In the model we identified that, in addition to the so-far dominant perspective on resource flow strategies presented in the literature (see e.g. Pieroni et al., 2019), the degree of the transformation in the value creation and capture of the company is extremely relevant. In our diverse forerunner cases across varied industries, we identified no cases where incremental innovation in value creation and capture led to the closure of resource flows, suggesting that radical business model innovation is necessary for radical improvement toward circularity of resources. We also found that data collection technologies could only catalyze incremental improvements to both resource efficiency improvements and value creation and capture, while implementation of data integration and analysis technologies could catalyze more radical improvements on both dimensions. This contributes to the extant discussion of digital technologies in CE literature by explicating how the technology types (Alcayaga et al., 2019; Pagoropoulos et al., 2017; Rosa et al., 2020) are connected to companies' ability to improve the circularity of their business while creating and capturing economic value.

### 5.3. Managerial implications

For managers seeking to capture the potential of the simultaneous economic and environmental improvements promised by circular economy, understanding the four key types of business model innovation for CE catalyzed by digital technologies is highly beneficial. The ability to implement these types is dependent on the digital capabilities of the firm, and data integration and analysis technologies are crucial for achieving radical improvements. Managers of firms that have not yet implemented digital technologies to improve the circularity of their business need to acknowledge that, while implementing data collection technologies is necessary for capturing value from CE, they alone mostly facilitate capturing value through cost reductions and the narrowing and slowing of resource flows. However, capturing this value only requires incremental changes to firms' existing business models, and thus is easier to attain. Managers planning to leverage digital technologies to capture value through the closure of resource flows need to recognize that data collection technologies must be complemented by data integration and analysis technologies and, most crucially, radical business model innovation.

### 5.4. Limitations and future research

Our study relied on purposefully chosen cases. Therefore, we acknowledge that the specific case selection limits the generalizability of the study. However, through rigorous case sampling based on maximum variation to capture a broad set of CE business models and support from expert interviews, we aimed to improve the external validity of the study, enabling generalizable conclusions to be potentially drawn (Eisenhardt, 1989). Furthermore, the qualitative nature of the methodology selected is suspect for researcher bias; we aimed to mitigate this risk by employing particular methods, including theory-based coding (Yin, 1994) and researcher triangulation (Flick, 2004).

As our study mainly focused on industrial businesses, further research should be conducted to provide insights into consumer-facing business models, where consumer acceptance of CE business models is of concern (Tunn et al., 2019). In this area, the literature on sharing economy, closely related to CE, has already made advancements in creating value through platform-based business models with regards to the role of digital technologies (Täuscher and Laudien, 2018). Furthermore, more empirical research regarding the value-creating role of digital technologies is required to test the findings of our qualitative case study further.

## Declaration of Competing Interest

No potential conflicts of interest were declared by the authors.

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