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Emergence and Dynamics of Circular Economy Ecosystem

Sustainable Residual Resource Management Enabled by Digital Technologies

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Abstract

The circular economy ecosystem (CEE) offers the potential to effectively manage the pressing issue of residual resources, encompassing waste and by-products that pose a challenge to our planet. Among various organizational forms, the ecosystem approach has emerged as the preferred method, fostering cross-industry collaboration to sustainably address residual resources. While business and innovation ecosystems have been extensively studied to understand their emergence, structure, and value proposition, they only provide a partial understanding of how CEEs come into being and manage these resources. Furthermore, CEEs encounter constraints from linear economic practices and environmental conditions. Given the prominent role of digital technologies within CEEs, this study delves into their influence, aiming to uncover their multifaceted impact beyond technical aspects.

This thesis sheds light on the distinctive factors driving the emergence of CEEs and how they differ from business and innovation ecosystems. Additionally, it explores the cohesive role played by digital technologies, extending beyond their conventional functions. This exploration is rooted in two case studies, one CEE in Africa and one in Europe. Both cases were selected due to their effective management of residual resources through sustainable approaches, coupled with their incorporation of digital technologies.

The findings of this research indicate that CEEs arise as a response to the need for coordinated collective action in the face of linear constraints and the necessity to access interdisciplinary knowledge. The pursuit of interdisciplinary knowledge takes precedence over economic considerations and competition due to the intrinsic motivation to acquire complementary knowledge. In addition, digital technologies act as a unifying force facilitating knowledge appropriation during experimentation, fostering cooperation among stakeholders, rather than promoting competition.

This thesis is positioned at the intersection of sustainable transitioning of strategic management and information systems.

Keywords: circular economy ecosystem, residual resources, management digital technologies, business ecosystem, strategy, knowledge appropriation, ecosystem renewal

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With heartfelt appreciation,
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List of Appended Studies

Study A:

Title: The Emergence of a Circular Additive Manufacturing Ecosystem from a Circular Economy Initiative

Heathcote-Fumador, I.E., Cepa, K., Teigland, R.

Presentation: Process Study Symposium - PROS 2023 held in June 2023 at Chania, Greece.

Submission: Submitted to Long Range Planning Journal - A special issue on Strategies for Sustainable and Circular Ecosystems on 1st October 2023.

Contributions: Collected and analyzed data, conceptual development, writing of the paper, developed the process model

Study B:

Title: From Business to Data Ecosystem: Investigating Data Ecosystem Emergence within a Business Ecosystem

Heathcote-Fumador, I.E., Cepa, K., Teigland, R.

Presentations:

1. Act Sustainable Conference 2022 organised by Gothenburg University and Chalmers University of Technology in November 2022 at Studenternas Hus, Gothenburg.

2. Swedish Winter Challenge 2023 held by the Sustainable World Corporation at a workshop focused on Waste to Resources through Entrepreneurship in January 2023, Gothenburg.

I intend to improve this paper for submission to the Information and Organisation Journal

Contributions: Collected and analyzed data, conceptual development, writing of the paper

Table of Contents

1 Preamble Reflection from the Study

"Life can only be understood backward but must be lived forward." - Soren Kierkegaard.

Imagine if your life began when you were already an adult, and that very day marked the planet's last day. Earth could no longer sustain us, and you struggled to breathe as trees couldn't provide oxygen, and all life was fading away. Witnessing the last tree's demise, you experienced how every organ and cell perished in a cascade until the final breath. But in that very moment of death, you were resurrected, transported back to the beginning of the planet when everything was lush and fresh. From the heavens, the voice of the creator speaks, saying, "I give you a second chance to live and care for this planet".

In this new opportunity, how would our approach to life change? How would we approach education, businesses, strategies, management, and technologies? Would we still advocate for individualistic growth and unhealthy competition among students, businesses, and researchers? If we discovered a way to preserve life, would we hide the truth from others to maintain a competitive advantage and achieve a monopoly? It seems absurd that we would hold an antidote for saving the world and patent it, forcing those who wish to contribute to saving the world to pay exorbitant amounts to participate.

In the present time, we humans have witnessed the repercussions of our actions, and many of us have seen paradise vanishing before our eyes. Realization is dawning upon many that our way of life must change. This second chance calls for us to reverse our actions and regenerate nature so it can care for us and our unborn generation.

2 Introduction

Living organisms, such as animals and trees, coexist and interact in a dynamic equilibrium known as a biological ecosystem. A forest is an example of this concept, characterized by a complex and interconnected web of living organisms and their environment that functions as a self-sustaining unit. At the heart of the forest ecosystem are the trees, often towering giants that serve as primary producers. Through photosynthesis, trees capture sunlight and convert it into energy, producing oxygen and storing carbon dioxide. These trees provide habitat and shelter for countless organisms and create a shady microclimate under their canopies that influences factors such as temperature and humidity. The forest is home to various animal species that thrive in unique niches. Herbivores such as deer and rabbits feed on leaves, fruits, and vegetation and depend directly or indirectly on the energy produced by the trees. Predators, such as lions or wolves, hunt these herbivores and thus ensure a natural balance in the ecosystem. Smaller creatures such as insects and rodents play an important role as decomposers, breaking down dead organic material and returning nutrients to the soil to enrich it for trees and plants.

The circular economy promoted by the Ellen MacArthur Foundation (EMF, 2013), shares similarities with natural biological ecosystems, characterized by their regenerative nature and eliminating waste by promoting resource reuse and within closed-loop cycles (Geissdoerfer et al., 2017). Moore (1993) used the biological ecosystem as a metaphor to explain the business ecosystem concept. However, it is paradoxical that while the business ecosystem is modeled after the biological ecosystem, waste has never been a consideration in the equation of business ecosystems. Instead, the predominant linear economy model has been followed, where natural resources are extracted, products are made, and sold, and little thought is given to the end of the product's life cycle. This approach does not reflect a holistic application of the principles found in the natural biological ecosystem, leading to the depletion of our natural resources and dire consequences for the planet.

The recognition of this issue has prompted global action, such as the 2030 Sustainable Development Goals (SDGs) (Keeble, 1988; United Nations, 2015). Soon after the SDGs, the European Union launched the Circular Economy Action Plan (Bourguignon, 2016) and later the Green Deal (Commission, 2019). SDGs Goal number 12, responsible consumption and production, aligns with the principles of the circular economy, advocating for recycling, reusing, and reducing waste (Geissdoerfer et al., 2017).

However, Moore's (1993) business ecosystem concept primarily focused on competition among complementaries for customers and income generation, neglecting the value of waste as a resource for other companies. This oversight stems from the linear economy mentality of the produce-use-dispose model, which assumes unlimited resources and disregards the potential of waste as a reusable resource. Collaboration becomes even more critical, particularly when one company's waste can be utilized as raw materials by another. It becomes evident that no single company can sustain itself in isolation, emphasizing the need for collective efforts to achieve the desired outcome of a circular or waste-free ecosystem, where waste is minimized or not even realized due to its consumption by other businesses. Circular economy ecosystems (CEEs) are emerging as a new form of ecosystemic organization to manage residual resources, serving as a counterpoint to linear business ecosystem practices. (Aarikka-Stenroos et al., 2021). However, they are constrained by the dominant linear economic practices. These ecosystems operate differently from business ecosystems in terms of their prioritization of profit returns and environmental impacts. They also manage different types of resources, which in turn reflect their goals and value propositions. CEEs manage residual resources (i.e., waste and byproducts), while other businesses within business ecosystems delegate their waste to public waste management organizations (Patala et al., 2022). Although they are also ecosystem organizational forms, their operations counter the status quo of the linear system. This presents them with challenges referred to as the "green prison" (Pacheco et al., 2010). These challenges coupled with their sense of responsibility (Brown et al., 2019) instigate joint efforts among actors to innovate and manage residual resources sustainably.

Business ecosystem studies may not be able to explain how CEEs emerge to manage residual resources because of their differing setups. Research into the peculiarity of CEEs is gaining attention; however, most researchers build their foundation from business ecosystems that have different goals and do not face the same challenges as CEEs (Aarikka-Stenroos et al., 2021; Konietzko et al., 2020).
Studies have found that digital technologies, such as blockchain, additive manufacturing (3DP), and AI, also play a role in enabling the circular economy (Chari et al., 2021, 2022) due to their generativity and programmability (Yoo et al., 2010, 2012). However, within the CEE, there is little understanding of the roles these digital technologies play as they are embedded in complex social settings.

To address this gap, this thesis aims to investigate how residual resources are sustainably managed in a CEE and the role of digital technologies as they are increasingly embedded in their operations. To achieve this aim, I have formulated two research questions (s): 1) How does circular economy ecosystem emergence to manage residual resources sustainably differ from business ecosystems? 2) What is the role of digital technologies in the circular economy ecosystem beyond technical functions? To answer these questions, I draw on two appended studies.

Study A‘s findings include the strategies adopted by a circular business to overcome the constraints of the linear economy as it tries to recover residual resources. One of the major strategies was to structure its circular business ecosystem and value chain to enable the recovery and remanufacturing of residual resources. Other strategic responses included manipulation, avoidance, and defiance (Muñoz & Dimov, 2015; Oliver, 1991). The residual resources were discarded fishing nets (PA 6 nylon plastic) in the harbors of Portugal. The study highlights the importance of the CEE to enable resource recovery, as well as the 3D printing technology that enables the joint recovery and remanufacturing of discarded fishing nets into furniture with superior added value.

Study B’s findings include the dual orchestration of both actors' management of residual resources and a data ecosystem. To enable coordination of the resource flow, they used digital technologies to support information capacity and reduce the complexity of the business ecosystem. Digital representation and information about the residual resources available to all actors allow them to easily exchange resources and monitor their activities concerning residual resource recovery. The residual resources were mainly discarded plastic waste from food and water packaging in Ghana.

This thesis is at the intersection of strategic management and information systems and contributes to sustainable transition for both strategic management and information systems literature i.e. green IS and green strategic management. Moreover, this thesis provides practical implications for managers and policymakers who are involved in sustainable or twin transitions.

The rest of the paper is structured in the following format: First, I provide a theoretical background on circular economy residual resources, draw on the business ecosystem, and present the role of digital technologies in CEE. This is followed by a discussion of the methodology, summaries of the two papers, and a discussion of theoretical contribution, practical implications, limitations, and areas for future research.

3 Theoretical Background

3.1 Circular Economy and Residual Resources

The concept of circular economy aims to reduce waste and minimize environmental impacts by promoting resource reuse within closed-loop cycles(Geissdoerfer et al., 2017). Geissdoerfer and colleagues (2017) highlighted that circular economy shares similarities with sustainable development, as both require intergenerational commitments, business model innovation, system change, interdisciplinary research, and system design and innovation. The circular economy concept originated from different schools of thought such as cradle-to-cradle and performance economy, and can be traced back to 1970. On the other hand, sustainable development emerged from the Brundtland Report in 1982 (World Commission on Environment and Development, 1987). However, the circular economy is still a highly contested concept (Korhonen et al., 2018) as there are diverse opinions on its meaning and approach to implementation from both practitioners and researchers, despite the agreed value and goal by all stakeholders. According to Korhonen and colleagues (2018), the circular economy is in the process of becoming a new paradigm. For a paradigm shift to occur, two events must take place. The first stage is the "paradigmatic, metaphoric, and normative" stage, which focuses on culture, norms, and change. The second stage is the "descriptive, positive, and analytic" stage, which focuses on the practice of circular economy such as measurements, tools, and benchmarks. The current literature and knowledge on the circular economy are mostly focused on the natural sciences and engineering, which means that we are at the second stage of the practical aspect, while social sciences studies such as organizational learning, strategy, and management are not yet prominent in the current literature (Korhonen et al., 2018).

A circular economy ecosystem (CEE) is defined by Aarikka-Stenroos and colleagues as "communities of actors that are hierarchically independent yet interdependent and heterogeneous, collectively generating a sustainable ecosystem outcome" (Aarikka-Stenroos et al., 2021, p. 261). CEE follows the principles of the circular economy and is an organizational form archetype that focuses on the sustainable management of residual resources. These are waste materials or by-products that are left over after a process or activity is completed.

Residual resources, often dismissed as insignificant in a linear economic context, are considered valuable within circular systems (Patala et al., 2022). They undergo recovery, reuse, recycling, or transformation into new products or energy sources. For instance, fish waste can be converted into animal feed, cosmetics, and biofuels; municipal solid waste can be subjected to recycling, composting, or energy conversion; geothermal brine can extract metals, minerals, and hydrogen; spent pot lining can be repurposed as a cement additive or fuel (Finger et al., 2021). These resources offer potential as inputs for other processes or products within a circular economy structure, aligning with the overarching aim of minimizing waste and environmental impact by resource reuse within closed-loop cycles (Geissdoerfer et al., 2017; Ghisellini et al., 2016). The effective management of these residual resources is pivotal not only for sustainability goals but also for enhancing overall resource efficiency.

The study of residual resources spans various disciplines, including environmental science, engineering, economics, and policy. Some of the cross-disciplinary studies have concentrated on the challenges and opportunities associated with harnessing residual resources for bioenergy and bio-based products (Gontard et al., 2018; Hamelin et al., 2019). Others have explored the evolution and vision of the circular bio-based economy (CBE), which transforms residual biomass into value-added products (Lange et al., 2021). Furthermore, research has compared the sustainability aspects of biodiesel production using different types of residual oils (Costa et al., 2013; Singh et al., 2019). These diverse studies underscore that managing residual resources necessitates an interdisciplinary approach that draws insights from various domains.

Consequently, the sustainable management of residual resources possesses a systemic nature, relying on collaborative efforts within ecosystems that span diverse interdisciplinary industries (Aarikka-Stenroos et al., 2021; Brown et al., 2019; Harala et al., 2023). However, a comprehensive understanding of how these ecosystems effectively handle residual resources sustainably, especially in a world largely influenced by linear economic practices, remains incomplete.

3.2 Drawing on Business ecosystems to advance Circular Economy Ecosystems managing Residual Resources

Business ecosystems have emerged as a response to firms' imperative to maintain profitability and competitive advantage through collaborative innovation across multiple industries (Moore, 1993). These ecosystems are made up of interindustry co-evolving actors and revolve around innovations, which then become integrated into subsequent rounds of innovation. Since the inception of the term by Moore (1993), ecosystems have gained widespread usage in various contexts, albeit with slight variations. For firms entering these ecosystems, the core aim is to sustain competitiveness and profitability (Adner, 2006; Moore, 1996, 2006).

In contrast, an innovation ecosystem involves interconnected entities encompassing both producers and users, all linked to a central firm or platform that generates and appropriates novel value through innovation (Autio & Thomas, 2014; Granstrand & Holgersson, 2020). While both business ecosystem and innovation ecosystem participants strive for profitability through innovation, the distinction lies in the locus of innovation: the innovation ecosystem is centralized on one focal firm's product, whereas the business ecosystem is decentralized with different products from individual firms. Prominent instances of innovation ecosystem include Google, IBM, and Apple.

In the business ecosystem and innovation ecosystem context, innovation, the creation of customer-facing value, and economic value emerge as consistent themes within ecosystem studies. These perspectives also underscore that there isn't a one-size-fits-all approach, and ecosystems can be structured and adapted to address diverse innovation and value-creation objectives. As articulated by Gawer (2014), ecosystems and platforms represent evolving structures that empower agents to innovate, compete, and generate value.

The intricate challenge of effectively managing residual resources mentioned above in a sustainable manner necessitates a cross-disciplinary understanding such as natural sciences and engineering and collaborative efforts within a well-structured business ecosystem and innovation ecosystem ecosystem. The question arises: Can the previously mentioned business ecosystem and innovation ecosystem ecosystem perspectives be tailored to address this challenge?

There's an increasing need to investigate why organizations engage in collaborative circular innovation within a circular ecosystem. As highlighted by circular economy scholars (Brown et al., 2019), collaboration in this context often stems from the identification of waste-related issues and a sense of responsibility. This factor significantly influences the selection of partners. The essence of collaborative circular innovation predominantly revolves around exploiting knowledge for material recovery and leveraging existing knowledge (Brown et al., 2020). However, these collaborative endeavors can face setbacks when the pursuit of individual economic benefits, such as intellectual property rights, takes precedence over striving for ecosystem-level value creation to facilitate circular economy goals. This inclination towards profit-oriented strategies, revealed by strategic management research (Teece, 1986, 2018), poses a hindrance to the advancement of sustainable development. Teece's (1986) study delves into strategic options like licensing and IP protection, demonstrating how these approaches can yield innovation-related profits by capitalizing on the strengths of external firms, all while keeping a focus on core competencies. However, the profit-centric motives of actors often obstruct progress toward sustainable transition and sustainable innovations as evidenced in Brown and colleagues' (2020) paper.

Actors operating within the CEE must strike a balance between traditional economic requirements and the distinctive demands of the circular economy. CEE's innovation is related to sustainable innovation 2.0 (Dyck & Silvestre, 2018), which places paramount importance on environmental and sustainable impact over mere economic value. This endeavor is complex, given that actors are entrenched in a logic that prioritizes profit and IP (Brown et al., 2020), making it challenging to pivot towards a more circular perspective.

Despite the circular economy's deviation from traditional business ecosystem priorities, circular economy scholars are actively driving advancements by drawing inspiration from established business ecosystem literature and charting new paths for future exploration. For instance, to comprehend the ecosystem perspective of circular economy innovation, Konietzko and colleagues (2020) adapted principles from business, innovation, and service ecosystems (Koskela-Huotari et al., 2016) to the circular economy context. They introduced three main categories of principles for circular ecosystem innovation: 1) Collaboration, which centers on fostering interactions between firms and other ecosystem participants to advance circular practices; 2) Experimentation, involving structured trial-and-error processes to enhance circularity; and 3) Platformization, focusing on using online platforms for social and economic interactions to promote circularity. This approach contributes valuable insights for achieving circular outcomes through an ecosystem perspective.

Similarly, Aarikka-Stenroos and colleagues (2021) introduced a typology for CEEs. This typology extends existing ecosystem research (business, innovation, entrepreneurial, and knowledge ecosystems) to the realm of circular ecosystems, categorizing them based on the flows of material and energy, knowledge, and economic value. While this typology aids in defining perspectives for circular economy research, it also poses challenges due to the distinct focus on residual resource management and the deprioritization of economic returns inherent in circular ecosystems. This deviation from traditional linear practices complicates the comparison.

Examining the challenges within CEEs, limited research has explored the intricate dynamics involving stakeholders, regulations, and market influences that shape residual resource management. Patala and colleagues (2022) delve into this realm by adopting a polycentric governance approach. In such a structure, multiple decision-making centers operate independently yet collaborate, coordinating actions and sharing resources. This approach introduces the concepts of mutual adjustment, collective agency, and resource sharing as the foundational elements of polycentric governance.

Therefore, effectively managing residual resources within a circular economy context necessitates a multidisciplinary approach and collective agency prioritizing environmental impact. The business ecosystem perspective offers valuable insights, yet adaptation and innovation are required to overcome the unique challenges posed by residual resources and circular practices. As circular economy scholars draw inspiration from established concepts while charting new territories, a more comprehensive understanding of circular ecosystems and their dynamics will emerge, potentially paving the way for more sustainable resource management.

3.3 Circular Economy Ecosystems are Emergent

The exploration of CEEs presents a relatively nascent research area, marked by a limited comprehension of the contextual dynamics. As such, there exists a significant need for further empirical studies to uncover the intricacies of CEEs, particularly in terms of their emergence and their adept management of residual resources to achieve ecosystem-level outcomes. Examining how these ecosystems come into being becomes a pivotal focus of this research, accentuated by the necessity to distinguish between the paradigms of business ecosystems and innovation ecosystems. The understanding of circular ecosystem emergence holds relevance not only for environmental concerns but also for ecosystem architects (Daymond et al., 2022), those who shape and govern ecosystem structure and dynamics. Their expertise is indispensable in structuring ecosystems that seamlessly and efficiently manage residual resources within a circular framework.

To bridge this knowledge gap, insights can be gleaned from business ecosystem studies, which have delved into the emergence of ecosystems across various contexts. Moore's (1993) conceptualization outlines four stages of ecosystem emergence: birth, expansion, leadership, and self-renewal. In a similar vein, (Adner, 2017) underscores the role of ecosystems as structures facilitating value creation by interdependent actors. He proposes three phases of emergence: alignment, activation, and adaptation. Building on this foundation of innovation ecosystem scholars, Jacobides and colleagues (2018) argue that ecosystems consist of actors bound by rules and roles, a concept articulated through four mechanisms: modularization, standardization, integration, and reconfiguration.

While these studies offer valuable insights into the emergence of ecosystems within innovation contexts, they fall short of addressing the unique challenges and opportunities presented by circular approaches to residual resource management. Thus, it is crucial to extend and adapt these frameworks to the intricacies of CEEs. Environmental factors, such as resource availability, pollution levels, regulatory pressures, and consumer preferences, play a pivotal role in the emergence and evolution of circular ecosystems (Brown et al., 2020; Patala et al., 2022). The role of stakeholders, including their dynamics and influences, also warrants consideration.

Yet, despite highlighting the necessity of collaborative efforts for managing residual resources within circular economies, these studies do not elucidate the process through which such endeavors arise and evolve. Aarikka-Stenroos and colleagues (2021) recognize this gap, underscoring the need for future research into the emergence of CEEs – a question that remains open.

This licentiate strives to address this gap by delving into the emergence process of CEEs, particularly in their pursuit of sustainable residual resource management.

3.4 The Role of Digital Technologies in the Circular Economy Ecosystem

Digital technologies can be defined as applications of digital science. Notable examples of these digital technologies encompass the Internet of Things (IoT), blockchain, AI, and Additive Manufacturing (Awan et al., 2021; Chari et al., 2021, 2022). These technologies have achieved a pervasive presence and strategic significance within companies, empowering them to forge novel paths of value creation, delivery, and capture (Mata et al., 1995; Yoo et al., 2010) Moreover, their potential extends to play a pivotal role in facilitating the implementation of a circular economy (Moreno et al., 2016; van Schalkwyk et al., 2018). These technologies are distinguished by unique characteristics that can effectively underpin circular ecosystems. These traits include programmability, malleability, and generativity (Yoo et al., 2010, 2012). Programmability relates to the capability of digital technologies to be reconfigured and customized to suit various contexts and needs. Malleability denotes the adaptability of digital technologies, allowing them to be modified and transformed by users and developers. Generativity, meanwhile, highlights the proficiency of digital technologies in generating new products, services, and processes that were hitherto unforeseen. These characteristics collectively can equip digital technologies with the agility and innovative potential necessary for addressing the intricate challenges posed by the circular economy.

On one hand, digital technologies have served as the infrastructure for building circular economies through the repurposing of their functionalities from diverse sectors. For instance, blockchain, a distributed information technology, facilitates the recording and verification of transactions by a network of nodes without a central authority (Azzi et al., 2019). Its application within supply chain systems has enabled traceability, transparency, and accountability. Notably, research by Böhmecke-Schwafert and colleagues (2022) asserts that blockchain technologies furnish the circular economy with an infrastructure role, rather than serving as an all-encompassing solution for resource recovery. Similarly, IoT has found use in the shoe industry through additive manufacturing (3D printing), producing shoes equipped with IoT capabilities that signal users when repairs are due (Moreno et al., 2019). While these technologies present challenges such as data standards, limited battery storage, and consumer acceptance, they have still proven valuable for advancing the circular economy. Additionally, AI has exhibited its worth in reverse logistics within circular entrepreneurial ecosystems, conferring benefits across diverse functions and tasks (Wilson et al., 2022).

On the other hand, digital technologies also propel the circular economy by fostering platform ecosystems or multisided marketplaces that facilitate the exchange of used products and recycled materials (Cusumano et al., 2019; Gawer, 2022; McIntyre et al., 2021). Illustrative examples encompass platforms like Facebook Marketplace, while others cater to data ecosystems, supporting knowledge management (Soldatos et al., 2021). Certain platforms function as product-service systems, propelled by the sharing economy concept, which encourages reuse and leasing instead of ownership (Bressanelli et al., 2018; Frey et al., 2019; Hamari et al., 2015; N. Wang et al., 2020). Conversely, data platforms serve as repositories for product life cycle information, accessible to stakeholders across the value chain (Walden et al., 2021).

However, the influence of digital technologies on CEE sustainability remains uncertain. Scholars focusing on innovation ecosystems and economic activities expound on how technological innovations and managerial approaches drive evolution within ecosystems (Holgersson et al., 2022). This evolution can either integrate ecosystems into focal firms or disperse them into the market (Holgersson et al., 2022). Additionally, the concept of a data ecosystem characterized as a network of autonomous actors that generate, consume, or provide data and other resources, presents challenges for data governance such as ownership, privacy, quality, and access (Lis & Otto, 2020, 2021). Data governance issue presents more ambivalence with the transition of private data from centralized to decentralized ownership and decision-making. This also necessitates establishing clarity regarding which elements should be decentralized and distributed (Lee et al., 2019; Vergne, 2020) for the sustainability of the digital ecosystem.

While the introduction of digital technologies has been observed to simplify complexities and fulfill informational requirements within ecosystems through digital representation (Wang, 2021) the core objective of a CEE revolves around the sustainable management of residual resources. It is imperative to ascertain the role digital technologies play in enabling complex actors to achieve their goals within this context. The innovation focus of a CEE is inherently oriented towards residual resources, which might demand innovative digital tools. While platform and data ecosystems typically emphasize innovations that complement the focal platform or are derived from data traces respectively, the potential innovations that the CEE, with its focus on residual resources, could ignite, different "wakes of innovations" (Boland et al., 2007).

Hence, there is a pressing need to gain novel insights specific to the use of digital technologies for the management of residual resources. These insights possess value not only for the broader digital technologies literature but also for the realm of Green Information Systems. Furthermore, comprehending the distinct challenges posed by digital technologies to CEEs, particularly concerning the need for additional digital skills, ensuring data quality, and fostering stakeholder engagement, lacks attention (Tavera Romero et al., 2021). As an illustration, a proposed framework by (Rosa et al., 2020) evaluates the digital readiness of circular economy initiatives, positing that digital technologies can amplify the efficacy, transparency, and scalability of circular economy practices. Furthermore, practitioners must be attuned to the potential risks that digital technologies might introduce to CEEs, particularly in terms of data governance and the ecosystem's overall sustainability.

To address this void, the present Licentitate formulates the following research question: What role do digital technologies play in the emergence of circular ecosystems for the sustainable management of residual resources? The paper delves into the intricate interplay between digital technologies and CEEs, illuminating their potential, challenges, and ramifications for sustainability and governance.

4 Methodology

In this section, I discuss the research design of the two studies appended. They were mainly qualitative studies primary data collected through interviews and secondary data through archival, and observations.

4.1 Study A

4.1.1 Research Design

We conducted a longitudinal process study (Langley, 1999; Langley et al., 2013) on Peniche Ocean Watch (POW), a circular economy initiative located in Peniche, Portugal. POW serves as an interesting case to examine strategies for integrating circular businesses into established linear models and showcases the journey of a circular firm's survival through orchestrating a business ecosystem. The initiative started in June 2018 with the primary objective of revitalizing economic activities in Peniche through a digitally enabled circular economy approach. They aimed to leverage digital technologies like additive manufacturing (3D printing), blockchain, Artificial Intelligence (AI), and the Internet of Things (IoT).

The study spans from June 2018 to March 2023. It began with the creation of Ocean Tech Hub (OCT), which resembled a Silicon Valley tech hub, focusing on the blue circular economy and developing innovations to remove ocean waste. They also initiated Circular Ocean, a recycling process. However, after research and ideation, they established another company called Narwave in Sweden, which focused on selling recycled materials and eventually using them to print boat hulls or furniture for boating. Unfortunately, this approach did not yield the expected results, leading to the creation of Ekbacken Studios to produce high-end furniture from compounded plastic derived from discarded fishing nets.

Throughout their circular business journey, POW collaborated with numerous partners who were inspired to join their circular economy mission. To sustain their operations and advance their research, they secured funding from Vinnova, the Swedish government's innovation funding agency. The successful funding enabled them to conduct further research, enhance their innovation and technology, and scale their initiative in collaboration with their partners. The project, named OCEAN-LSAM, involved forming an ecosystem with different companies dedicated to producing high-quality furniture from recycled discarded fishing nets.

4.1.2 Data Collection

To conduct a process case study with a mixed data collection approach (Langley, 1999), I aimed to capture intricate details to develop a comprehensive report on the evolution of events over time (refer to Table 1). The investigation into this case officially began in November 2022, initiated by the first and second authors.

Type of Data	Aim	Number
1. Interviews	Retrospective Accounts	13
2. Secondary Interviews from media coverage and during partner selection	Plans and motivations	7
3. Social Media Posts:	- Plans and outcomes - Event announcements - Understand when they called for collaborators	50

LinkedIn Posts – Autumn 2020 to April 2023, Youtube (Ted talk), Slideshare		
4. Observation	Work environment and enthusiasm	3
5. Meeting notes	Plans and action	15
6. Archival Materials	A vision of and strategy for the initiative, operational plans	100
7. Email Threads	Conversation of plans, problems actions and outcome	5

The primary data source consisted of 20 interviews conducted with various participants involved in the additive manufacturing project, companies located in Portugal, as well as the pioneers and other individuals who have been part of the circular initiative since its inception. Secondary archival data was provided by the third author. Noteworthy, the third author cofounded the POW and from the outset, she diligently documented all meetings and gathered archival materials to conduct a future investigation into this case as a circular economy initiative. Additionally, I enriched our data by incorporating social media posts from project members and involved companies (e.g., Linkedin and Facebook). This approach helped us verify the timing of events, track various activities, and understand the development of ideas and initiatives over time.

4.1.3 Data Analysis Process Study

We used a process ontology, a philosophical standpoint that perceives the world as constantly evolving and undergoing transformations (Tsoukas & Chia, 2002), to explore how sustainable entrepreneurs (SEs) create circular value ecosystems as a means to break free from their limitations ("green prison") (Pacheco et al., 2010) and address sustainability challenges.

During our analysis, we followed four distinct stages. Initially, we used AEON Timeline software to create a detailed chronology of events and milestones from the value proposition to the first value creation. This helped us understand the micro steps that took place before any event occurred and gain insight into the temporal development of the case. Through this, we identified the main players, the activity of stakeholders and companies, and the entry and exit of partners throughout the process.

In the second stage, we engaged in retroduction and empirical corroboration, updating timelines based on the data and posing essential questions. We examined the challenges encountered during the circular product development process and the strategies employed by sustainable SEs to overcome constraints imposed by the dominant linear economy practices.

The third stage involved identifying the constraints specific to each phase of circular economy product development. We referred to the concept of a "green prison" (Pacheco et al., 2010) from the literature on sustainable entrepreneurship to understand how these constraints led to the evolution of interlinked CEEs.

In the final stage, we delved into the SEs' strategies in response to the identified constraints. Using the lens of "organizational becoming" (Tsoukas & Chia, 2002), we examined the micro-steps and actions taken by the SEs to overcome challenges and adapt their plans to different linear practices. These efforts led to transformative changes within the organization.

The journey of the SEs through four circular economy product development phases - waste recovery, ideation, prototyping, and scaling - emerged from our analysis. We present our empirical findings in the subsequent section. Through this reflective process, we gained valuable insights into the complexities and dynamics of building CEEs, shedding light on the strategies employed by SEs to navigate the challenges imposed by the linear economy.

4.2 Study B

4.2.1 Research Design and Data Collection

We conducted a case study of Ghana, Africa, a multistakeholder waste recovery initiative, as it is an example of a CEE initiative developing a digital platform across the entire supply chain. The initiative describes itself in the following way: "The Waste Recovery Platform has the objective to connect key stakeholders in the waste management value chain to promote waste recovery in a larger circular economy context. It builds on two key fundamentals: a) the journey towards a circular economy requires collaborative problem-solving, engagement, and partnerships across all stakeholders; b) for a circular economy to thrive, the availability of data and information is essential.

Ghana faces a significant waste issue, with more than 30,000 tonnes of solid waste and 3,000 tonnes of plastic waste generated daily, and 75% of this waste is either burned or dumped in public areas. The Waste Recovery Platform initiative involves more than 300 participants from various organizations and encompasses four dimensions: a physical convening mechanism, a digital platform, a promoter of innovation, and communication.

The digital platform incorporates several tools, such as a waste resource map and a compendium of technologies, designed to provide real-time information and data on waste management and facilitate material exchange. Specifically, the platform aims to promote the circular economy through the following six aspects:

a) Connecting stakeholders and improving information flows to strengthen coordination and collaboration.
b) Providing a space for engaging citizens in Reduce, Reuse, and Recycle (3Rs) principles.
c) Offering scientific-based data and tools for planning and investment.
d) Facilitating stronger connections between the formal and informal waste sectors.
e) Enabling new types of collaborations between research institutions and the private sector for developing and testing innovative waste solutions.
f) Demonstrating the economic, social, and environmental benefits of sustainable waste recovery business models, encouraging further testing and adoption of technologies and innovative solutions on a larger scale.

To collect data, we reached out to individuals from different types of organizations involved and conducted interviews with 19 respondents, using a semi-structured approach. The interviewees represented the following organizations: orchestrator (3 interviews), NGOs (3), CSO (1), waste recyclers (5), waste recovery companies (3), government (1), pioneering team (3), financial support (1), and business capacity building (1). Additionally, we collected data from secondary sources, such as publicly available documents and data provided by the interviewees.

ID	Type of Organization	Number of People	Number of Interviews	Duration of Interview
O1, O2	Development Organization (Orchestrator)	2	O1(1) O2(2)	1hr 40 min
N1, N2, N3	Non-governmental Organization	3	N1, N2, N3	3hrs 20min
C1	Civil Society Organization	1	C1	44 mins
WA1, WA2, WA3, WA4, WA5	Entrepreneur (Waste upcycling)	5	WA1, WA2, WA3, WA4, WA5	4hrs3mins
WB1, WB2, WC3	Entrepreneur (Waste recovery and selling)	3	WB1, WB2, WC3	3hrs
GOV1	Public Institution	1	GOV1	54 mins
P1, P2	Pioneering Team (Orchestrator)	2	P1 (2) P(1)	121 mis
F1	Funding Partner	1	F1	38 mins
B1	Business Capacity Building Partner	1	B1	41 mins
Total		19	22	17hrs 1mins

4.2.2 Data Analysis - Grounded Theory

During our research, we chose to adopt a grounded theory induction approach, as suggested by Gioia and colleagues (Gioia et al., 2013). Rather than imposing preconceived notions or theories on the data, we allowed the information to reveal itself to us. This method encouraged us to listen attentively to what the data had to say, fostering a more reflective and open-minded perspective.

My journey began with open coding, following Strauss and Corbin's method (Strauss & Corbin, 1998). I took charge of coding two interviews, which were then reviewed and discussed with the other two co-authors. This collaborative process ensured that the initial coding was not biased by a single perspective.

The other two co-authors independently coded two interviews to maintain proximity to the informants' accounts. Subsequently, we compared, discussed, and clarified the coded concepts, striving to preserve the authenticity of the participants' narratives. We employed the web version of Atlas. ti for collaborative coding, where all co-authors had the opportunity to review and comment on each other's coding. This open and transparent approach helped us refine the coding further.

As a result of the open coding phase, we generated a substantial number of first-order codes, totaling 445. These codes were then subjected to iterative processes, involving merging, splitting, and changes, following our evolving understanding of the case, as proposed by Gioia and colleagues (2013). Simultaneously, we utilized axial coding, following Strauss and Corbin's framework (1998), to organize the first-order concepts into 31 cohesive themes. These themes were then grouped into 10 overarching second-order themes, providing us with a comprehensive structure for our findings.

Throughout the research process, we engaged with relevant literature on business ecosystems, data ecosystems, and stakeholder theory. This interdisciplinary approach and iterative refinement allowed us to derive aggregate dimensions and ultimately shaped the final data structure.

4.3 Paper Summary

The study took two angles to understand the circular economic ecosystems. Study A focuses on the emergence of the CEE from how sustainable entrepreneurs build an ecosystem of circular businesses to manage residual resources to circumvent and fit the dominant linear economy business environment while Study B looks at how central orchestrating organizations purposefully develop and deploy digital technologies to coordinate the emergence of circular business activities.

Studies A and B answer the research question (RQ1): *How does the Circular economy ecosystem emergence to manage residual resources sustainably differ from the business ecosystem and innovation ecosystem?* Revealing the process of the emergence of the Circular economy ecosystem.
What role do digital technologies play in the emergence of circular ecosystems for the sustainable management of residual resources?
Both Studies A and B help to answer (RQ2): *What is the role of digital technologies in the circular economy ecosystem beyond technical functions?* Showing how the role of digital technologies in the CEE goes beyond technical functions.

4.3.1 Study A: The Emergence of an Additive Manufacturing Circular Economy Ecosystem

This research explores the challenges and strategies faced by sustainable entrepreneurs while establishing circular businesses within the prevailing linear economy business ecosystems. In a world dominated by a linear economy, sustainable/circular businesses encounter several constraints, which Pacheco and colleagues refer to as the "green prison" during their establishment (Pacheco et al., 2010).

The specific case under study involves a business model focused on recovering discarded PA6 plastic fishing nets from the environment and remanufacturing them into furniture using 3D printing technology.

Our primary objective was to distinguish between the general constraints typically faced by all start-ups and the constraints that are unique to circular businesses. Subsequently, we aimed to identify the strategies employed by these businesses to address these constraints. To achieve this, we adopted the perspective of "organizational becoming" (Tsoukas & Chia, 2002), which emphasizes the analysis of microscopic changes to unveil the underlying strategies driving organizational transitions. This approach significantly influenced our data collection and analysis processes. We utilized diverse data sources, such as interviews, archival materials, reports from websites, as well as social media posts and videos of interviewees, to ensure an accurate depiction of events and triggers.

Among the numerous strategies identified, we found the following to be peculiar to circular businesses. These included: 1) the clash of value systems, i.e., the contrasting perspectives on waste and resource; 2) the clash of logic, i.e., the tension between decentralization and economies of scale; and 3) the clash of workers' ideals, i.e., the conflicting perceptions of clean and dirty job roles within the circular business model.

Our analysis of the data uncovered several strategies that have been documented in the literature. For example, when confronted with pressure to achieve economies of scale, the circular businesses in our study employed the avoidance strategy (Oliver, 1991) by tactfully shifting certain operational aspects to a more suitable location, such as moving from Portugal to Sweden, which was conducive to decentralization. Decentralization allowed these businesses to collaborate with other firms, share costs, and jointly manage residual resources, thus facilitating the gradual formation of an ecosystem.

Furthermore, in response to the linear economy's insistence on injection molding for economies of scale, a process that often generates excessive waste, these businesses adopted the defiance strategy (Oliver, 1991). Instead, they embraced 3D printing technology, which not only enabled small-scale production but also facilitated remanufacturing and customization, thus aligning with circular principles.

Regarding the clash of value systems, the strategy observed was manipulating (Oliver, 1991) the system using tactics that leveraged influence through collective action (Aldrich & Fiol, 1994; Pacheco et al., 2010). This approach allowed circular businesses to navigate conflicts arising from divergent perceptions of waste and resources, seeking to create alignment and understanding.

Notably, whenever the linear system favored circular businesses during funding applications, they chose to conform (Muñoz & Dimov, 2015), also known as acquiesce (Oliver, 1991), as it did not negatively impact their operations. By strategically conforming to certain aspects while retaining their core circular principles, these businesses effectively balanced their sustainability objectives with the demands of the prevailing linear economic environment.

One effective strategy that arises from all of the aforementioned strategies is to establish partnerships. This strategy is integral to all the strategies mentioned above. And will enhance the alignment strategy within the business ecosystem literature, involving the coordination of physical resources and product stewardship. This approach involves gradually aligning multiple partners to create a CEE, with a focus on recovering and utilizing residual resources. Unlike the conventional approach of aligning complementary partnerships within an innovation ecosystem, this method transcends mere innovation and complementarity. Instead, it encompasses the entire process of managing residual resources throughout the ecosystem. Enabling a circular flow of resources includes both tangible, intangible, and residual resources.

The core objective of this approach is to establish a self-sustaining circular business model where resources are continuously regenerated, reused, or remanufactured, significantly reducing waste and environmental impact. It reflects a shared sustainability vision among the partners involved, demonstrating a collective commitment to achieving a more environmentally responsible and resource-efficient economic model. By implementing this strategy, firms can actively contribute to a more sustainable and regenerative economic system, fostering long-term environmental and product stewardship and economic viability.

The study also revealed that the process of becoming a CEE is dialectic, thus it emerges out of a synthesis of the collision of the circular practices (anti-thesis) of the actors and the linear economy system practice (thesis). This causes the evolution we see today as many businesses refuse to follow the linear practices with support from several policies and environmental advocates pushing for the change. The linear economy is still dominating but survival strategies such as manipulation, insurgence, and avoidance cause the new circular ecosystem to emerge and over time this circular ecosystem will be the norm.

4.3.2 Study B: The Emergence of a Data Ecosystem from a Circular Business Ecosystem

The study examines the emergence of data ecosystems in CEEs aimed at tackling the complex problem of waste resource management. Employing Gioa's three-stage coding and qualitative data analysis (Gioia et al., 2013), the outcome was a grounded model elucidating the dual alignment and orchestration of the business and data ecosystems to maintain stakeholder engagement. The orchestrators' intent to collect data for waste recovery monitoring necessitated the motivation and attraction of actors through the promised access to resources such as funding and capacity-building. The data collected created a digital representation of their activities and thus gave rise to the data ecosystem. A data ecosystem is a group of loosely coupled, autonomous actors with different roles that facilitate the sharing and exchange of data and other resources, with the quality of relationships between actors driving engagement in the ecosystem (Oliveira et al., 2019).

Furthermore, the data ecosystem facilitated the business ecosystem by affording derivative digital innovations (Yoo et al., 2012), including the Waste map, Contact directory, and a website. This symbiotic relationship established a feedback loop, wherein data collection in the business ecosystem fed into the data ecosystem, empowering the business actors to search for resources and connect with potential partners for waste reuse and remanufacturing. This virtuous cycle of data exchange and network effects amplified the overall value and growth of both ecosystems.

One of the primary contributions of this research is in alignment mechanism, encompassing waste material resources, people, and data, thus alignment of both the business ecosystem and data ecosystem. The study also unearths the agency of digital technologies within the circular ecosystem. Moreover, the findings reinforce stakeholder theory (Phillips et al., 2019), asserting that effective alignment mechanisms influence stakeholder engagement in business ecosystems and foster contributions to the data ecosystem.

In addition to the stakeholder theory, this study enriches the theory of information ecology by highlighting the necessity of relevant data collection for decision-making and coordination in complex ecosystems (Mckinney & Yoos, 2010; P. Wang, 2021). Digital technologies and datafication play a pivotal role in the liquefication of information (Normann, 2001), which enables the creation of new value and sustenance for business actors operating within the ecosystem.

In conclusion, this study provides valuable insights into the emergence and orchestration of data ecosystems to address plastic waste in business ecosystems. The contributions encompass dual alignment and orchestration, stakeholder theory, and advancements in information ecology, thus offering substantial implications for research and practice in circular economy and waste resource management in a business ecosystem.

4.4 Comparison of the two studies

Construct	**Study B**	**Study A**
Orchestration	Loosely-Coupled	Tightly-Coupled
Ecosystem process	From Affiliated to Structured	From a Single firm's entrepreneurial initiative to structured ecosystem
Location of the plastic wase	Ghana	Portugal
Residual Resources	Plastic bottles and packages, Animal waste	Discarded Fishing net
Material Level	PPE, LDPE	PA6 Nylon
Companies producing the product producing waste	Plastic bottling companies, sachet plastic water packaging, Soft drinks companies	Fishing Nets Companies
Location of the companies producing the products that became waste	Ghana, China	China
Ecosystem Leader	International Development organisation	Single Circular business

Digital Technology	Digital platform, waste map , mobile waste exchange app, online directory	3D printing Robot, Computer Simulations 3D designing software Robot Programming
Actors	Entrepreneurs, small to medium size companies, Large and established waste mnangement firms, public organisations, researchers, NGOS	Entrepreneurs, start ups, research institute, established firms, researcher, Swedish firms,
Location of the digital Technology	Online (accessible online)	3d technology(Sweden) Sales (online)
Owners of the residual resource	Many actors own their respective waste recovered by them selves.	One Residual resource flows through multiple actors
Owners of the digital technology	Ecosystem Leader	One of the Actors
Funding for the activities	Ecosystem leader and private organisation	Swedish Government Research Group, Ecosystem leader - Startup
Ownership of the digital technology	Orchestrator	Research Institute of Sweden, RISE
Complementary Assets	Data, knowledge, Residual resources, Economic Value, Funding	Residual Resources, Knowledge, Funding
Value	Upcycled residual resources into various prodicts such as building blocks for constructions, Planting pots, Plastic lumber, Bus stop design, Furnture	Remanufactured into luxurious furniture with beautiful custom designs
Challenges	Mismatch value systems for residual resources, Material challenges connectin with expectees, Data related challenge and changing roles.	Mismatch value systems for residual resources, Material challenges connectin with expectees, Technological challenges with 3D printing, robot, programing and the 3D designs.
Emergence	Sustainable management of residual resources, and need to collect the data to aid in coordination and monitoring. Need to allocate funding to support small to medium size circular businesses to managing residual resources	Sustainable management of residual resources. Need to the gather expertise to sustainably manage resources with 3d printing technologies. And partnership with established firms who have capital to purchase a 3D printer.

5 Discussion

This research investigated two cases of CEEs that sustainably manage residual resources. Both cases organized their activities differently. They both provide insight into how a CEE emerged to sustainably manage residual resources and the role of digital technologies in enabling them to achieve their goals. I answer two questions: *RQ1) How does Circular economy ecosystem emergence to manage residual resources sustainably differ from business ecosystems? RQ2): What is the role of digital technologies in the circular economy ecosystem beyond technical functions?*

The thesis makes two contributions to the emergence of business ecosystem studies with a circular economy context to manage residual resources sustainably. And one contribution to the green information system studies with the circular economy context. First, they emerged as a result of strategic responses aimed at counteracting prevalent linear economy constraints through coordinated collective action. Secondly, they integrated to meet the need to access interdisciplinary knowledge. This knowledge needs shift collaborative dynamics from competition and economic gains to cooperation.

Finally, the embeddedness of digital technologies within the CEE assumes the role of a conduit for the acquisition of knowledge, owing to their inherent generative capacities, functioning through a dual mechanism. On one hand, the knowledge engendered through digital technologies diffuses to the individual actors within the ecosystem, consequently informing subsequent innovative undertakings at the firm level. On the other hand, the newfound knowledge acquired by ecosystem actors operates as a synergistic complement to innovation endeavors within the ecosystem framework.

5.1 CEEs emerge from Strategic responses to linear economy practices through coordinated collective action to manage residual resources.

This research enriches the ecosystem organizational form perspectives by offering insights into the distinctive realm of effectively managing residual resources sustainably. Notably, the business ecosystem and IE frameworks have not previously addressed strategies to confront the challenges posed by the linear economy due to their integration within the linear system.

The contribution of this study lies in its exploration of the limitations of the business ecosystem perspective in capturing the intricate dynamics surrounding residual resources within CEEs. Unlike the business ecosystem perspective, which primarily leverages resources and capabilities for value proposition and relies on firm-level resource orchestration, the CEE introduces a novel boundary resource in the form of residual resources. This boundary resource not only sets the CEE apart but also provides a distinctive lens for ecosystem management.

A significant revelation of this study is the recognition of residual resource acquisition and management as pivotal aspects of CEEs. This realization unveils a previously unexplored ecosystem perspective that diverges from the traditional business ecosystem viewpoint. The new viewpoint is the peculiar challenges confronting CEEs that do not affect business ecosystems. While the latter can easily acquire additional resources through market transactions, the former grapples with boundary resources privately owned by public organizations or industry entities, thereby evading the traditional market-driven coordination through pricing mechanisms.

In contrast to the strategic scholars' proposition of innovation-centric approaches for business ecosystems, CEEs are confronted with complex linear practices that undermine the perceived value of residual resources. Consequently, their strategic responses are intricately intertwined with the institutional environment, encompassing uncertainties stemming from ambiguous residual resource availability and access. This thesis uncovers these nuanced challenges and sheds light on the multifaceted nature of strategic activities within CEEs.

Both appended studies demonstrate the challenging process of managing residual resources in a CEE, requiring distributed agency (Aarikka-Stenroos et al., 2021), collective action (Pacheco et al., 2010), polycentric governance (Patala et al., 2022), and sustainable innovation 2.0 (Dyck & Silvestre, 2018) to prevent harm to our planet. This resonates well with previous research that sustainably managing residual resources is optimal for an ecosystemic collaboration with many actors from different disciplines (Brown et al., 2019; Harala et al., 2023; Patala et al., 2022). This is in line with the definition provided that CE ecosystems are "*communities of hierarchically independent, yet interdependent heterogeneous set of actors who collectively generate a sustainable ecosystem outcome*" (Aarikka-Stenroos et al., 2021).

However, the papers also highlight a major challenge in the ecosystem: the lack of value for residual resources (waste and byproducts) and the lack of systems to encourage sustainable recovery of residual waste. For instance, Study A, encountered a lack of access to plastic waste as they were privately owned by the municipality's waste sector. Similarly, in Study B, the actors faced challenges in recovering plastic waste because they were not properly separated from households to the municipal level and waste management companies to allow for recycling and reuse.

The actors in both appended Studies A and B employed extra strategies and tactics of influence (Oliver, 1991) to convince either the authorities or the community to access plastic waste. Similarly,(Patala et al., 2022) have also cited additional challenges to the management of residual materials. There is a lack of continuous supply of these residual materials, leading to a lack of scale (Bansal & McKnight, 2009). Furthermore, as waste is managed by public organizations, there is a need to constantly involve the public in reusing and recycling residual resources (Laukkanen & Patala, 2014). This was evident in the two studies and they highlight that collective action of influence and defiance (Oliver, 1991; Pacheco et al., 2010) played a role in their access to their plastic waste. Studies A and B had to strategically engage the public actors to succeed in their endeavors. In terms of the lack of a constant supply of waste, studies A and B revealed the residual resource was in abundant supply as long as the linear economy practices continue but it can present a situation of limited supply when negotiations are ongoing to convince the owners. Also because the organizational processes to collect, treat, and distribute them are not as organized, it requires coordination of collective efforts of autonomous circular ecosystem actors.

To reiterate, circular and sustainable businesses struggle within a linear-oriented economy. These struggles of ecosystems are rarely discussed in prior business ecosystem studies. This is because most actors in business ecosystems do not consider waste and by-products as part of the resources nor do they consider them in their value proposition for their innovations. I conjecture that the lack of attention to residual resources is a result of linear economy practices (take-make-dispose) influenced by resource theories from the 1980s. According to those theories resources can be broadly defined as everything that reflects a firm's strengths and weaknesses (Wernerfelt, 1984). They are the various inputs or assets at a firm's disposal, including capital, labor, technology, raw materials, and intellectual property. These resources are heterogeneous and are imperfect mobility across different companies (Barney, 1991). They can refer to assets or factors that contribute to a firm's capabilities or competitive advantage and can encompass tangible and intangible assets (Hunt, 1997). Waste from various businesses is then delegated to waste management companies (Patala et al., 2022). However, actors within the CEE include residual resources in their resource portfolio and have a sense of responsibility to recycle them into new materials and products (Brown et al., 2019). As a result, they created their separate ecosystem known as the CEE to overcome those constraints articulated as a "green prison" (Pacheco et al., 2010).

5.2 CEEs emerge through the need to access interdisciplinary knowledge and this overshadows competition and economic gains.

The findings show that the CEE facilitates collaborative learning among interdisciplinary actors, prioritizing knowledge access over competition and economic returns in contrast to business ecosystem studies (Moore, 1993, 2006). This is particularly distinct to the CEE due to the intricate nature of working with resources that pose challenges in understanding. Given the geographical separation between product producers and recyclers, a lack of information regarding the constituents of residual resources and the methods to recycle them at the material level persists. Consequently, unraveling the potential of residual resources to generate new value demands interdisciplinary collaboration, encompassing expertise on material components and experimental approaches.

Previous studies established modularity (Jacobides et al., 2018) and alignment (Adner, 2017) as causing the emergence ecosystem which is evidenced by the appended studies. However, the previous studies focus on complementary actors and innovation with limited attention to the residual resource circularity as a new driver for modularity and innovation. In study A the ecosystem aligned partners with diverse knowledge to enable 3D printing of furniture from residual waste. In study B there were various kinds of experts in the ecosystem they each contributed with a piece of complementary knowledge or resources for managing residual waste.

Aarikka-Stenroos and colleagues (2021) described the three analytical categories of the CEEs to be material flow, knowledge, and economic value. However studies A and B can not be categorized into just one of the categories as proposed by Aarikka-Stenroos and colleagues (2021) This is because analytically there is an interplay between the three flows (material, knowledge, and economics). The material flow is always the constant circular economy due to the importance of material residual resources. For instance, in Study B, all three forms of flow were observed in the ecosystem but in Study A only two forms of flow occurred, the material flow and the knowledge. The economic value flow was not observed, because it was still in the pre-economic value stage and therefore the knowledge flow was more pronounced.

While residual resources contribute to maintaining a constant flow of materials in a CEE, the flow of knowledge and economic value appears to be a dynamic process that drives ecosystem evolution or enables its emergence. The flow of knowledge also exhibits 'strong complementarity" in both studies, as described by Holgersson et al. (2022), and therefore requires coordination in the CEE (Adner, 2017a; Holgersson et al., 2022). In contrast to previous studies where distributed knowledge was conceptualized as a "centrifugal force" (Holgersson et al., 2022) that limits the integration of actors due to the difficulty of attracting multiple distributed actors, in the context of a CEE, this distributed knowledge has proved to reinforce the "centripetal force" for the ecosystem to remain integrated. This could be due to the size of the ecosystem. The smaller it is, the greater the chance of attracting dispersed knowledge.

The inclusion of knowledge needs leads to new insights in ecosystem studies that require further empirical research. The dynamic presence or absence of knowledge needs can potentially lead to the disappearance or appearance of fundamental ecosystem elements, such as competition, as often observed in business and innovation ecosystem studies (Autio & Thomas, 2014; Granstrand & Holgersson, 2020; Moore, 1993). However, the evolutionary process from knowledge need to economic value appropriation is beyond the scope of this study. Additional empirical longitudinal studies may be needed to observe how changes in knowledge needs affect ecosystem dynamics.

5.3 Digital technologies facilitate knowledge appropriation through complementary learning motivation.

This thesis contributes to an enhanced understanding of the roles played by digital technologies within CEEs. The appended studies unveil that the embedding of digital technologies yields not only technical functionalities but also affords novel social roles. These roles facilitate knowledge appropriation (Ley et al., 2020), which in turn complements the value-creation process through complementary learning motivations (Cepa, 2021). This aligns with the observations of organizational scholars concerning the roles of big data technologies in inter-organizational collaborations (Cepa, 2021; Cepa & Schildt, 2019), encompassing learning motivation, mutual adaptation, and strategic learning. Similarly, embeddedness digital technologies trigger "wakes of innovations" within collaborative settings (Boland et al., 2007) and foster complementary learning motivations (Cepa, 2021).

As postulated (Cepa, 2021), learning motivation within the digital sphere deters competitive tendencies in favor of cooperative efforts, a characteristic that resonates with CEEs' focus on environmental impact and residual resources. In addition, when digital technology capabilities match local practices, positive interactions, and coordination dynamics occur (Oborn et al., 2019). For example, in study A, the capabilities of 3D printing technology within CEE were shown to be positively aligned with practices such as reuse and recycling, facilitating interactions, and knowledge appropriation.

Knowledge appropriation serves a dual purpose: bolstering the ecosystem-level value proposition and underpinning individual firms' subsequent innovations. This alignment aligns with Wang's (2021) research, asserting that all ecosystem organizational forms encompass both self-assertive (holons) and integrated (holarchy) actors. These actors act autonomously while pursuing private objectives yet contribute to ecosystem-level goals. As actors assimilate knowledge about digital technologies to support ecosystem-level value propositions, they simultaneously apply this knowledge to their individual firms, fueling their next product and innovation endeavors. This is empirical evidence of what Moore (1993) articulated "In a business ecosystem, companies co-evolve capabilities around an innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations". Study A exemplifies this statement, where programming actors within the CEE were motivated to realize the 3D printing of plastic material into furniture, and persistently invested efforts as they perceived potential applications in future projects in the individual organization. Even though knowledge access could make the firms in the CEE competitive in the market, cooperation is observed in Study A rather than competition.

Furthermore, the embedding of digital technologies has the potential to engender new ecosystems specific to the technologies themselves and the residual resource, a diffusion that traverses the entire ecosystem. Study B reveals the emergence of a data ecosystem within the CEE (Gelhaar & Otto, 2020; Lis & Otto, 2021; Oliveira & Farias Lóscio, 2018), while Study A highlights the emergence of an additive manufacturing ecosystem. These new ecosystems serve as breeding grounds for transformative initiatives, steering the CEE toward sustainable practices. The generativity intrinsic to digital technologies empowers actors to foster continuous learning and innovation, as they draw consistently from the knowledge to solidify their collective pursuit of circularity. As Wang (2021) posits, the intricate challenges faced by ecosystems necessitate digital technologies to support their informational and coordination needs.

The flow of novel knowledge not only complements ecosystem-level innovation but also signifies a shift in attention to the privacy concerns of shared data in their data ecosystem in a digital age. As evidenced in the studies, actors did not hold back knowledge or data from other participants. They agreed to contribute their data to a collective pull. Study B underscores that the management of waste sustainably and its environmental impact takes precedence over concerns related to trust, privacy, and ownership of private data. This could be attributed to the non-sensitive nature of the data in this specific context.

From a broader perspective, this study contributes to the dual orchestration of the socio-technical elements (Geels, 2010; Geels & Kemp, 2007) within the ecosystem, encompassing both human and technical (digital and material) aspects of residual resource management. The study elucidates that digital technologies introduce a novel dynamic warranting further investigation into new roles, identities, and capabilities, thereby enriching the understanding of CEEs' intricate dynamics in the digital era.

5.4 Towards Integrating circular economy ecosystem with the business ecosystem studies: Future studies

The results of the two studies show that knowledge flow and innovation are endogenous to CEEs, as well as existing ecosystem literature. This indicates that this field and practitioners are not far away from incorporating residual resources into their innovation agenda, especially in this age where firms are realizing the need to be circular. The reality of finite sources of raw materials as a result of linear economic practices and overutilized resources has dawned on many companies.

However, these CEEs face many systemic challenges imposed by linear practices. As posited by Aarikka-Stenroos and colleagues (2021), they are characterized by material flows that are constrained and enabled by their institutional and environmental conditions. Their process of emergence is dialectic, as evidenced by the process in Study A. They are constantly constrained by linear practices, also known as a "green prison" (Pacheco et al., 2010). Circular economy practices are anti-thesis to the linear thesis, and this collision is causing the evolution of many firms and ecosystems seeking renewal (Harala et al., 2023; Kaipainen & Aarikka-Stenroos, 2022).

In contrast, current digital technologies and expertise can be repurposed toward aggressively sustainably managing waste through innovation. The distributed agency also fuels the flow of materials, knowledge, and economic value, as the agency moves from a single actor to many actors as knowledge is created and recreated to materialize the value proposition. This is consistent with the innovation ecosystem literature, where ecosystems produce outcomes that are impossible with one actor (Adner, 2006, 2017; Bogers et al., 2019).

Therefore, for wider-scale practice of reuse and reduction of waste to occur, the circular conversation should start right from the beginning of the production. This will be an ideal case rather than circular economy businesses being left to do the hard work of recycling the continual waste generation. If waste is designed out of production and consumption (Kiørboe et al., 2015; Prieto-Sandoval et al., 2018; The Ellen MacArthur Foundation, 2012), it will be a true mimicry of the biological ecosystem and it can help avoid uncertainties in circular economy ecosystem face. This resonates with ideas from supply chain scholars who also propose a circular supply chain by design and intention, where the forward and reverse supply chain should be designed to ensure more reuse and repair rather than by chance which presents challenges of unpredictable returns and insufficient value (Amir et al., 2022).

Indeed, the focus of the literature on business ecosystems has predominantly revolved around the actors and innovation within the ecosystem, often overshadowing the crucial resource aspect. This disparity becomes particularly evident when we draw parallels between business ecosystems and their biological counterparts. Biological ecosystems offer a valuable perspective on the utilization and conservation of resources. One of the key principles observed in natural ecosystems is the efficient reuse of waste as resources for other organisms, thereby minimizing waste and promoting sustainability. This principle, known as ecological efficiency, highlights the interconnectedness and interdependence of organisms within an ecosystem.

From the findings of this study, I propose a novel approach to renew business ecosystem studies, by incorporating the environmental perspective, which is often neglected in current research. Instead of expanding the theory to another archetype with unique characteristics (Dzhengiz et al., 2023), as done for the CEE, I aim to improve the foundational constructs of ecosystem organization literature. This way, I can avoid the criticism of pouring new wine into old wineskins (Scaringella & Radziwon, 2018) that this archetype may face. In contrast, my approach is aligned with Bogers and colleagues' (2019) argument that to advance this field, ecosystem types must be abstracted, and the ecosystem should be analyzed as the unit of analysis.

5.5 Practical Implications

To further enhance the insights provided, I recommend implementing the following practical implications. Firstly, those overseeing the CEE should ensure that all participants possess a shared understanding regarding the utilization, valuation, and ownership of residual and bottleneck resources (Gueler & Schneider, 2021). This can be achieved through collaborative workshops and creating a compelling vision based on previous successful cases. It is important to note that this should not only be done during the initiation of the CEE but should also be incorporated into the long-term management structure to promote sustained engagement and integration. As management mechanisms have the power to either integrate or disintegrate an ecosystem, it is crucial to have a comprehensive and adaptable approach (Holgersson et al., 2022).

To effectively implement a CEE, digital tools should be flexible and adaptable to local needs. Orchestrators must ensure that residual resources can be repurposed in different ways to meet specific demands. For example, 3D printing of furniture from discarded material can be used to produce products that are valuable in a local context. In Ghana, 3D-printed classroom tables and chairs are highly needed for children in poor communities, while in Sweden, it could be luxurious furniture. APIs can be implemented to encourage bottom-up access and development, leveraging the generativity of digital platforms to extend recycling knowledge.

However, digital technology can also create bottlenecks and dependencies if key technology is controlled by a single actor. To avoid such dependencies, ownership of digital infrastructure should be addressed beforehand. By implementing flexible and adaptable digital tools and addressing ownership concerns, CEE can be effectively managed and sustained.

5.6 Limitations and Future Research

One of the limitations of this study is that it relied mainly on qualitative data and interpretative analysis. Although the analysis was systematic and followed widely accepted qualitative methodologies that ensured rigor such as grounded theory (Gioia et al., 2013) and process studies (Langley, 1999; Langley et al., 2013), it is possible that some biases and subjectivity influenced the results. For example, the interviews and observations may have been affected by the rapport between the researcher and the participants, the choice of questions and probes, and the interpretation of the responses and behaviors. Moreover, my personal background and philosophical orientation may have shaped the research design, data collection, and analysis. To address this limitation, I engaged in joint analysis with co-authors who had different perspectives and expertise and also used triangulation of data sources and methods to enhance the validity and reliability of the findings.

Another limitation of this study is that it was context-specific and may not be generalizable to other settings or situations. The two studies were conducted in a particular industry and geographical region, which may have unique characteristics and dynamics that affect the phenomena under investigation. Therefore, the results may not apply or be transferable to other contexts or cases that differ significantly from the ones studied. However, this thesis aimed to provide rich insights and explanations based on existing literature and empirical evidence, rather than to produce universal laws or predictions. Thus, the results can be useful for practitioners and scholars who are interested in similar or related topics, and who can assess the relevance and applicability of the findings to their contexts.

The current studies focused more on the emergence of the CEE and the role of digital technologies in managing residual resources. However, there are still many aspects that need further exploration and explanation. In future studies, I intend to look more into unpacking the digital object of the two studies and the evolution of both ecosystems (Bresciani et al., 2022; Faulkner & Runde, 2019; Leonardi & Barley, 2010). I aim to understand how the digital object influences and is influenced by the actors, activities, and residual resources in the CEE, and how it enables or constrains the transition to a more sustainable mode of production and consumption.

Another direction for future research is to contribute to a theory that will renew ecosystem studies with sustainable practices and in so doing challenge some underlying resource-based view of firm theories towards extension of the resources to include residual resources. I argue that the CEE is not only a network of interdependent actors but also a system of value creation and capture that is based on the circularity of resources. Therefore, I propose to develop a theoretical framework that incorporates the concept of residual resources as a key element of the ecosystem, and examines how they are identified, transformed, exchanged, and utilized by the actors.

Finally, I intend to build a theory that reconciles sustainability to strategic management literature (Borland et al., 2016) I suggest that the CEE offers a new perspective on how firms can achieve competitive advantage and create shared value by adopting circular business models and practices. I plan to investigate how firms can leverage their capabilities, resources, and relationships to innovate and differentiate themselves in the CEE, and how they can balance their economic, environmental, and social objectives and outcomes.

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