THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Digitally Mediated Circular Economy Practices in Ecosystems

A Human-Material Tuning Practice Perspective

IDA EYI HEATHCOTE-FUMADOR

Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2025

Digitally Mediated Circular Economy Practices in Ecosystems
A Human-Material Tuning Practice Perspective

IDA EYI HEATHCOTE-FUMADOR
ISBN: 978-91-8103-307-6

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 5764
ISSN 0346-718X

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Telephone +46 (0)31-772 1000

Printed by Chalmers Digitaltryck
Gothenburg, Sweden 2025

Digitally Mediated Circular Economy Practices in Ecosystems

A Human-Material Tuning Practice Perspective

IDA EYI HEATHCOTE-FUMADOR

Department of Technology Management and Economics

Chalmers University of Technology

Abstract

As the transition to a circular economy gains momentum, digital technologies — such as IoT, AI, automation, and 3D printing — are increasingly recognized as essential enablers of circular practices. Several studies demonstrate that these technologies support circular economy initiatives, such as facilitating multi-sided markets involving waste generators and buyers, or serving as intermediaries. Digital technologies provide economic incentives to increase the value of waste materials and reduce waste, especially when these materials can be traded through mobile platforms. Research also indicates that digital capabilities can help address challenges associated with implementing circular practices.

However, existing studies often present a deterministic view of digital technologies in circular economy practices. They tend to separate their digital capabilities from the human actions that enable circularity and from the practical, physical requirements of managing waste and used materials. Furthermore, research on how digitally mediated circular practices emerge remains limited. As a result, there is a lack of understanding of how digitally mediated practices are enacted in the transition to a circular economy.

This thesis contributes to filling this gap by drawing on Pickering's concept of the "mangle of practice," adopting a human-material perspective to explore how digitally mediated circular economy practices are enacted and how physical waste materials, digital technologies, and circular principles are integrated into the process. It is based on a comparative interpretive qualitative study of two cases of emerging circular ecosystems in Europe and Africa, both characterized by a practice void where no established circular practices initially existed.

This thesis advances the growing research on digital sustainability and the circular economy, with broader implications for the fields of Information Systems and Strategic Management. The key contributions are threefold. First, it enhances circular economy research through a conceptual model that presents a human-material tuning — or mangle of practice — perspective on circular economy studies. Second, it extends the work on human-material tuning within the information systems literature by applying it to the context of the circular economy, where circular principles guide actors. In doing so, it moves beyond a deterministic view of the role of digital technologies in enabling circular practices. The study opens the black box of activities behind the scenes, demonstrating how practices emerge as digital technologies, physical materials, and social actors become mutually entangled in practice. Third, it offers insights into strategic management ecosystem orchestration by showing that developing a circular economy at the ecosystem level should be understood not only as a social effort but also as a dynamic human-material tuning process. It shifts the focus from human agency alone to the importance of circular principles, such as resource stewardship and material agency.

Keywords*:* *circular economy, digitalization, human-material tuning, circular ecosystem*

List of Appended Papers

This thesis is based on the following four appended papers:

1. Heathcote-Fumador, I.E. & Selander, L. (2025). Dealing with “Data Voids” in Emergent Circular Businesses. *European Conference on Information Systems (ECIS) 2025 Proceedings To be submitted to the Electronic Journal of IS in Developing Countries or ICT4D Journal.*

2. Heathcote-Fumador, I.E., Cepa, K., Teigland, R. *(Manuscript under review, Information & Organization)* Ecosystem Data Governance: Aligning Data Governance and Ecosystem Orchestration to Address Grand Challenges

   Previously published version:
   Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2025). The Alignment of Data Governance and Ecosystem Orchestration to Address Grand Challenges. *Academy of Management Proceedings, 2025*

3. Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (*Manuscript to be submitted to Organization & Environment*) Overcoming conflicting linear and circular logics: A process study of how rotating orchestration drives circular ecosystem emergence

   Previously published version:
   Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2024). Circular Ecosystem Emergence and Orchestration by Sustainable Entrepreneurs. *Academy of Management Proceedings, 2024*

4. Heathcote-Fumador, I.E. (*Manuscript*) Tuning Work as a Representation Mangle: Achieving Circular Production through Additive Manufacturing with Recycled Polymers

Acknowledgements

I never thought this day would come, given the countless times I considered quitting and seeking an easier path in life. This journey has been both impossible and incredible, testing me in every way imaginable. I did not walk through these tests as a champion, but as a deeply grateful person. To everyone who supported me—and yes, even to those who pushed me relentlessly into this “pond of crocodiles”—I owe my deepest thanks.

I am profoundly grateful to my supervisory team. Robin Teigland believed in me from the very beginning and selected me as one of her PhD students, a decision that transformed my life and career. Katharina Cepa from Vrije University joined as my co-supervisor in my second year, constantly challenging me to reach greater heights in my research. She also introduced me to valuable academic communities and conferences, which enriched my network and skills.

At every stage of my PhD journey, I received constructive feedback that helped me progress to the next level. I thank Michael Barrett, my licentiate discussant, for carefully reading my work and giving me clarity to improve my papers. I am also grateful to Attila Márton, my opponent during the final seminar, whose insights helped me refine my thesis. A special thanks goes to Ingrid Johansson Mignon, my research proposal discussant, who encouraged me early on to think critically about the definitions of my concepts. Beyond these formal engagements, I benefited immensely from the many discussions in the corridors of Entrepreneurship and Strategy, as well as the feedback from all my seminar participants and the numerous conferences I attended.

I would also like to thank Lisen Selander, who hosted me as a visiting scholar at Gothenburg University and co-authored a paper with me. Her invaluable support contributed to our paper being accepted at the European Conference of Information Systems (ECIS), a milestone that significantly enriched my research journey.

I would also like to express my gratitude to the United Nations Development Programme – Ghana, for granting me access to interview within their ecosystem and for reviewing the results. A heartfelt thank you to Catherine Adodoadji-Dogbe, who generously took time out of her busy schedule to support me in gathering the information I needed. My thanks also go to the organizations in Ghana, Portugal, and Sweden that welcomed me, allowed me to interview them, and shared their invaluable experiences.

To the Technology Management and Economics Department and the Entrepreneurship and Strategy Division, thank you for making me feel welcome. I have cherished our discussions and international experiences over lunches and fika. Special thanks to Susanne and Tomas for always being present, offering quick discussions on both academic and practical matters. I am also grateful to Anneli for her warmth and for my being me "Swedish teacher at the lunch table." My gratitude goes to Johanna for her genuine care and support, to Jashar for his wise tips, and to Anmar for our open conversations beyond academia. I especially appreciate Karen, Carina, Camila, Marcus, Marting, Henrikke, Tobias and Kristina for your kindness and support. Thank you, Anders, for your assistance and for the interesting discussions about YouTube videos and the use of AI in content creation. You have all made this journey more fulfilling and enriching.

I extend my gratitude to the Directors of Studies — Violetta, Karl, Ala, and Ceren and the administrative staff for their guidance and dedication in making my path smoother.

To my colleagues and fellow PhD students: thank you for sharing this journey. To Maria, for always listening and sharing moments that eased my burdens; to Adrian, for your constant check-ins and brainstorming sessions that helped me overcome writer's block; and to Martin, for inspiring me with your entrepreneurial spirit and farming adventures. I also appreciate Rabih, Malin, Tina, Kristoffer, Anton, Anna and many others for our memorable discussions over dinners and lunches. Another special thank you to Maryam Washik of the University of Oslo. You have been a constant source of inspiration and encouragement. Thank you for being my ranting partner — every time we spoke, we had the freedom to share everything that made us mad, happy, or sad. Together, we lamented over paper rejections and other setbacks, celebrated paper acceptances, and dreamed about life after our PhD degrees. I truly cherish all those moments.

I am also grateful to the Church of Christ in Sweden for encouraging me with hope in the promises and the Word of God, and for praying with me throughout this PhD process.

My deepest gratitude goes to my family. To my father, Stanley Hayford Fumador, who long wished for me to earn a PhD but sadly passed away just two weeks before I began this journey — I hope you are proud. To my mother Davida, and my siblings Ira, Ivan, and Irene, as well as my in-laws — Theresa, my mother-in-law, and my sisters-in-law Gloria, Sara, Dorcas, Mercy, and Jemima — and my extended family in Ghana, thank you for your love and encouragement.

Finally, to my husband, Isaac Arnold McSey — my heartbeat, my lifeline 💙. You sacrificed your own academic dreams to ensure I could reach the finish line. You did double or triple the work to cover for my absence during conferences, work trips, and intense writing seasons. You witnessed my tears, stress, and exhaustion, yet still stood firmly by my side, encouraging me through every low point. You are indeed the “worst offender” for pushing me, but without you, I would not have made it. To my boys, Royce and Leroy — my angels — you woke me up before the alarm, kept my mind sharp with your endless questions, and reminded me of life’s joys beyond academia.

I cannot mention all the names here, but if our paths crossed during my PhD studies, please know that I am truly grateful for your contributions and support.

To all of you — thank you. You turned what seemed like an impossible journey into an unforgettable one.

Ida

Chalmers University of Technology
Gothenburg, Sweden
October 2025

Table of Contents

Definitions of concepts used in this thesis

Concept	Definition
Circular Economy	“a regenerative system in which resource input and waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops”(Geissdoerfer et al., 2017).
Tuning / Mangle of practice	Tuning or mangle of practice is how human and material agencies are adjusted and coordinated during scientific and technological work. (Pickering, 1993)
Circular principles	Systemic thinking, value creation, resource stewardship, and resilience ISO 59004 (2024) or eliminate waste and pollution, circulate products and materials, and regenerate nature (EMF, 2013).
Circular Strategy	These strategies are referred to as the R strategies: R0: Recover, R1: Recycle, R2: Repurpose, R3: Remanufacture, R4: Refurbish, R5: Repair, R6: Reuse, R7: Reduce, R8: Rethink, and R9: Refuse.
Resource Strategies	Resource strategy refers to the environmental goals of the circular business model: narrowing, closing or slowing resource loops (Bocken et al., 2016).
Slowing resource loops:	“Through the design of long-life goods and product-life extension (i.e. service loops to extend a product’s life, for instance through repair, remanufacturing), the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources.” (Bocken et al., 2016, p. 309).
Closing resource loops:	“Through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources.” (Bocken et al., 2016, p. 309).
Resource efficiency or narrowing resource flows:	“aimed at using fewer resources per product.” (Bocken et al., 2016, p. 309).
A Practice	“embodied, materially mediated arrays of human activity centrally organized around shared practical understanding” (Schatzki, 2001, p. 2).
Circular Practice	Embodied, materially mediated arrays of human activity in which human, and physical material agencies are continually adjusted and coordinated, through shared understandings of circular principles, all aimed at sustaining resource value across organizational and ecosystem contexts.
Digital innovation	“is the carrying out of new combinations of digital and physical components to produce novel products.” Yoo et al. (2010, p. 725)
Digitally mediated Circular Practice	Embodied, materially mediated arrays of human activity in which human, digital, and physical material agencies are continually adjusted and coordinated through shared understandings of circular principles, all aimed at maintaining resource value across organizational and ecosystem contexts.
Sociomateriality Practice	The space in which multiple human (social) agencies and material agencies are imbricated (also called a “technical subsystem”) (Leonardi, 2012, p. 42).
Human-material Tuning	Is a process where human and material agencies are adjusted and coordinated during scientific and technological work.
Materiality	The arrangement of an artifact’s physical and/or digital materials into particular forms that endure across differences in place and time and are important to users. (Leonardi, 2012, p. 42)
Sociomateriality	Enactment of a particular set of activities that meld materiality with institutions, norms, discourses, and all other phenomena we typically define as “social.” (Leonardi, 2012, p. 42)

1 Introduction

1.1 Research Motivation

Recent assessments using the planetary boundaries framework show that six of the nine boundaries have been transgressed, indicating that Earth is now operating well outside its safe operating space for humanity (Richardson et al., 2023). This escalating ecological crisis — marked by resource depletion, climate change, and unsustainable patterns of production and consumption — has intensified the call for systemic alternatives to the current economic model.

The circular economy (CE) has emerged as a widely endorsed approach to decouple economic growth from environmental degradation (Ghisellini et al., 2016). Prominent definitions conceptualize CE as "a regenerative system in which resource input and waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al., 2017). Policy frameworks such as the ISO 59004 (2024) standard highlight circular principles such as systemic thinking, value creation, resource stewardship, and resilience, and the Ellen MacArthur Foundation furthers these principles with three design-driven circular principles: eliminate waste and pollution, circulate products and materials, and regenerate nature (EMF, 2013). National strategies, such as the Netherlands' "10R" framework, further operationalize these ideas into specific strategies ranging from "refuse" to "recycle" (Potting et al., 2017).

While these frameworks are conceptually appealing and linked to clear environmental, economic, and social benefits (Hussain et al., 2020; Richardson et al., 2023; Steffen et al., 2009), the practice of CE remains fragmented and ambiguous. Implementation requires collaboration across organizational boundaries and often involves actors with no prior relationships (Aarikka-Stenroos et al., 2021; Kanda et al., 2021), yet efforts are hindered by resistance from incumbents and consumers (Kirchherr et al., 2018), dependency on external partners (Kanda et al., 2024; Vermunt et al., 2019), alongside knowledge and technological gaps, such as inadequate material data and insufficient expertise in durable product design (Geissdoerfer et al., 2023; Kanda et al., 2024).

Digital technologies — including the Internet of Things (IoT), artificial intelligence (AI), and blockchains (Chauhan et al., 2022) — and digital platforms are increasingly acknowledged as key enablers of the circular economy, that is, digitally mediated circular practices (Jose et al., 2017; Lopes de Sousa Jabbour et al., 2023; Pagoropoulos et al., 2017). They enhance material flow visibility, facilitate coordination, and support the reuse of waste.

For example, sharing platforms such as *Too Good To Go* (TGTG) reduce food waste by connecting providers with surplus food to consumers (Ranjbari et al., 2024). These platforms, functioning as "circularity brokers" (Ciulli et al., 2020), bridge circular "holes" by connecting residual resource sellers to buyers. Blackburn et al. (2023b) conceptualize such digital platforms as new forms of organizing for creating circular value. Their technological affordances help overcome circular business model (CBM) challenges (Blackburn et al., 2023a). CBMs can be analyzed through value proposition, firm-centric, and ecosystem-centric lenses (Ritala et al., 2023). While Industry 4.0 solutions (e.g., automation and analytics) support firm-centric CE strategies (Bag, Dhamija, et al., 2021; Bag, Gupta et al., 2021; Gupta et al., 2019; Kristoffersen et al., 2020), more complex R strategies (e.g., reuse and recycle) often demand an ecosystem-centric approach involving diverse actors and products (Zeiss et al., 2021).

1.2 Problematizing key assumptions

Despite the promise of Digital Technologies (DT) in enabling CE and popularity, digital technology for circular economy scholarship and practice often rests on **two implicit assumptions**: First, **Digital technology inherently accelerates CE transitions** — implying a largely deterministic relationship between technology adoption and circular outcomes. Second, **Concepts such as principles, strategies, and practices are clearly defined** — despite evidence that these terms are frequently conflated, leading to conceptual ambiguity.

These assumptions obscure essential dynamics in the implementation of CE, especially when it is digitally mediated. Digital tools such as IoT, AI, and blockchain are often celebrated for enabling CE by increasing material flow visibility, facilitating coordination, and supporting reuse (Chauhan et al., 2022; Ciulli et al., 2020; Lopes de Sousa Jabbour et al., 2023). However, this framing risks treating technology as a linear solution, overlooking the **physical materiality** of waste and resources that must interact with digital systems for circular practices to succeed.

Moreover, conceptual ambiguity in CE literature — particularly the interchangeable use of "principles," "strategies," and "practices" — makes it difficult to consistently observe and evaluate circular practices. Actions such as recycling are often presented without explicit reference to the principles (e.g., resource stewardship) that render them meaningfully circular. This lack of conceptual clarity contributes to **practice voids** in emerging CE ecosystems, where actors must invent new ways of working.

1.3 Research Aim

Unlike most CE–digital studies that assume digital technologies inherently accelerate circular economy transitions in a linear manner, this thesis challenges such deterministic views. It instead emphasizes the intertwined roles of **circular principles**, **digital materiality**, and **waste materiality** in shaping how circular practices emerge in real-world ecosystems.

The overarching aim of this thesis is to investigate how digitally mediated circular practices are enacted in circular economy ecosystems where organizations are attempting to develop and scale circular practices that involve digitally mediated recycling activities. These settings are characterized by a practice void, where existing practices are insufficient and new ones must be invented. To achieve this aim, this thesis poses the following research question: *How are digitally mediated circular practices enacted in emerging ecosystems that face practice voids?*

To address these issues, I draw on Pickering's (1993) concept of the **mangle of practice** and the notion of **human–material tuning** to reconceptualize digitally mediated circular practices as emerging from the **mutual shaping** of human actors, digital technologies, and physical materials. This ontological stance is particularly suitable for studying ecosystems where coordination is distributed and not dictated by a central actor (Aarikka-Stenroos et al., 2021; Lingens et al., 2021). It allows me to explore how digitally mediated circular practices are enacted, adapted, and stabilized over time, influenced by circular principles, and shaped by both digital tools and physical material resources.

1.4 Research Design

Empirically, the thesis is situated within circular economy ecosystems where organizations are attempting to develop and scale circular practices that involve digitally mediated waste recovery activities. These settings are characterized by a practice void, where existing practices are insufficient and new ones must be invented.

I used a qualitative interpretive comparative case study design, which allows for an in-depth exploration of dynamics, processes, and situated practices within a real-world context, typically within one or multiple organizations or systems (Eisenhardt, 1989; Walsham, 1995). The thesis draws on case studies of two circular ecosystems, in Africa and Europe. Both are committed to using digital technologies to enable a circular economy. Both cases focus on waste recovery, but the choice of technologies differs, and the dynamic between human and material elements, as well as geographical context — presenting polar types of sampling logic (Voss et al., 2002) — helps unravel the differences and provide more insight into digitally mediated circular practices. Out of the two case studies, four papers emerged to contribute to IS and strategic management research.

1.5 Contribution

This thesis adds to the growing research on digital sustainability and the circular economy. It also has broader implications for the fields of Information Systems and Strategic Management. The key contributions are threefold:

Firstly, the thesis contributes to circular economy research through the development of a conceptual model that presents a human-material tuning or mangle of practice perspective on circular economy studies. The model explains how digitally mediated circular practices emerge from the interplay between the *collective imagination* of actors and the *material prospecting* and *tuning of material resistances and human accommodations*, shaped by *circular principles*.

Secondly, it contributes to the information systems literature by extending the work on human-material tuning to the context of the circular economy, in which circular principles guide actors. It moves beyond the determinism of the digital technologies' role in enabling circular practices. I open the black box of activities behind the scenes, showing how circular practices emerge as digital technologies, physical material resources, and social actors are mutually entangled in practice. It also elaborates on the mechanism of tuning between digital materiality and waste materiality as a synchronization mechanism to match the limitations and physicality of waste materials with the flexibility and speed of digital capabilities, ensuring that waste materials are considered in the digitally mediated circular economy. This also means that digital innovation may need to slow down to incorporate constraints and requirements from waste materiality.

Thirdly, it contributes to the research on strategic management ecosystem orchestration by demonstrating that developing a circular economy at the ecosystem level should be viewed not only as a social endeavor but also as a dynamic human-material process. The empirical account positions digitally mediated circular practices as a mangle of human-material practices influenced by circular principles. It decenters human agency and places circular principles, such as resource stewardship, at the center, considering the performative works of humans and non-human digital and physical materials as intertwined and mangled in a dialectic of accommodation and resistance.

I argue that "tuning" is the more suitable term to describe and understand a circular economy ecosystem, rather than "ecosystem orchestration," which prioritizes humans' intentions to meet their own needs over the well-being of nature. The use of tuning in the context of the circular economy extends the realm of practice to incorporate the voice of resources, thereby mitigating environmental pollution and the depletion of our natural resources through circular principles. This extension of tuning to the circular economy contributes to the growing interest in research that focuses on the natural environment, aligning with Andrew Pickering's recent book, Acting with the World: Agency in the Anthropocene (Pickering, 2025). It emphasizes tuning human scientific practice to nature. Instead of acting with all our human intentions, we need to put nature at the center of everything and act in harmony with it. This will prevent the dark side of human agency that has caused unintended consequences, such as global warming, climate change, excessive waste, and carbon emissions.

1.6 Thesis Structure

Chapter 2 provides an overview of relevant literature.

Chapter 3 outlines my philosophical stance, research design, and context.

Chapter 4 presents a summary of the appended papers.

Chapter 5 discusses the findings from the appended papers and develops the conceptual model.

Chapter 6 presents the contributions the thesis makes, reflecting on its limitations, and proposes directions for future research, concluding the discussion.

The remainder consists of references, appendices, and appended papers.

2 Background

In this chapter, I present the background for this thesis and its research aim. Section 2.1 references a wide range of interdisciplinary, strategic, and environmental sources, providing the reader with a definition of the circular economy, its related concepts, and how earlier researchers have conceptualized the idea. Thereafter, sections 2.2 delve into how digital technologies are enabling the circular economy, aiming to understand the process, practice, and identify gaps in current studies.

2.1 Circular economy

2.1.1 Evolution, implementation, and benefits

The circular economy (CE) paradigm has established a niche within sustainable development research, with a bounded goal of ensuring sustainable resource management. CE is defined as "a regenerative system in which resource input and waste emission and energy leakage are minimized by slowing, narrowing, and closing the loops" (Bocken & Ritala, 2021; Geissdoerfer et al., 2017, p. 766). Slowing, narrowing, closing the material and energy loops, and regenerating nature are referred to as resource strategies in circular business models (CBMs) (Bocken & Ritala, 2021). These resource strategies "can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Bocken & Ritala, 2021; Geissdoerfer et al., 2017). They are built upon the foundational work of Stahel (Stahel, 2016) and McDonough and Braungart (McDonough & Braungart, 2002).

Bocken et al. (2016) clarify that slowing and closing the loop both contribute to resource cycling, while narrowing the loop focuses on resource efficiency. Slowing resource loops involves extending product life and utilization periods through the design of long-life products and service loops, such as repair and remanufacturing. Closing resource loops focuses on recycling materials between post-use and production phases to create circular resource flows. This approach aims to close the loop through material recycling but does not necessarily affect the speed of resource flows. Narrowing resource loops refers to using fewer resources per product through the implementation of efficiency measures. While this reduces resource use, it differs from slowing and closing loops as it does not address product longevity or material cycling (Bocken et al., 2016).

To operationalize these circular economy strategies, several R frameworks or strategies have been developed. For example, a policy report in the Netherlands by Potting et al. (2017)

introduces 10 R strategies as approaches enabling the circular economy. The 10Rs include: R0: Recover, R1: Recycle, R2: Repurpose, R3: Remanufacture, R4: Refurbish, R5: Repair, R6: Reuse, R7: Reduce, R8: Rethink, and R9: Refuse. These strategies range from highest to lowest priority: smart manufacturing/use (R0–R2), product lifespan extension (R3–R7), and recycling/energy recovery (R8–R9). While recycling is currently the most common strategy, higher-level strategies are preferred for achieving more substantial reductions in resource consumption and waste generation.

Scholars of CE strategy have introduced several frameworks to support businesses. For example, Bocken et al. (2016) offer a list of product design strategies, business model strategies, and examples to assist strategic decision-making. Bocken & Ritala (2022) present six pathways for building CBMs, acknowledging that many businesses lack established CE practices and need guidance either to adapt existing models or create new ones — whether through closed-loop resource management or collaborative resource sharing. Urbinati et al. (2017) provide a taxonomy of four CBM adoption modes based on two dimensions: customer value proposition and value network configuration. The *Linear Model* lacks circular practices in both dimensions, reflecting the traditional "take-make-dispose" approach. The *Downstream Circular Model* incorporates circularity in customer interaction (e.g., leasing, take-back schemes) but not internal operations. The *Upstream Circular Model* embeds circularity in internal processes without modifying customer engagement. Finally, the *Full Circular Model* integrates circularity in both internal operations and customer interactions, representing the most comprehensive and sustainable approach (Urbinati et al., 2017).

To develop circular business models (CBMs), firms must consider both resource strategies — narrowing, slowing, and closing resource loops — and innovation strategies, which can be either closed (firm-centric) or open (collaborative) (Bocken & Ritala, 2021). A *closed innovation strategy* involves implementing circularity within firm boundaries, providing greater control over product quality and resource reuse. Examples include internal resource reuse, packaging reduction (e.g., Apple), and take-back or recycling initiatives (e.g., McDonald's use of fryer oil for fuel). These enable firms to maintain direct process control and maximize value capture. By contrast, an *open innovation strategy* involves engaging external partners or customer communities to enhance circularity. Examples include second-hand platforms (e.g., H&M, Sellpy), community repair initiatives (e.g., iFixit), and industrial-scale circular practices (e.g., Interface's fishing net recycling program).

CE has direct benefits for environmental sustainability when organizations ensure the sustainable use of resources and the regeneration of nature. It also has indirect benefits for economic and social sustainability (Zhu et al., 2010), benefiting both businesses and society. For example, businesses operating with "waste-to-energy" CBMs that close the loop internally convert their food waste into energy through anaerobic digestion, capturing additional value from leakages in their business activities (Hussain et al., 2020). This leads to environmental benefits, clean energy usage, and a competitive advantage. Mobile waste sales platforms such as Rapel (Kurniawan et al., 2022) and food waste platforms such as *Too Good to Go* reduce environmental waste while also creating economic value from waste (Ciulli et al., 2020; Ranjbari et al., 2024).

2.1.2 Challenges in CE Implementation

While the conceptual promise of the circular economy (CE) is widely endorsed (Korhonen et al., 2018), realizing its practical application remains complex, particularly in multi-actor settings where coordination is distributed and evolving. CE transitions and innovations are closely related yet conceptually distinct. CE transitions represent the broader shift from linear to circular resource use across product chains, whereas CE innovations refer to specific tools or mechanisms that facilitate these transitions. Potting et al. (2017) identify three types of CE transitions: those driven by radical technological change, those focused on socio-institutional change with minimal technological input, and those requiring both socio-institutional transformation and enabling technologies such as digital infrastructures. Potting et al. (2017) argue that the main challenges in CE transitions are predominantly socio-institutional rather than technological. These include overcoming entrenched consumption patterns, established production methods, and prevailing business practices. The most significant barrier is *socio-institutional lock-in* — the persistence of existing ways of doing business and consuming. Further challenges include coordination failures, where economic actors struggle to forge joint solutions and establish new relationships within value chains. Companies also face risks in implementing circular revenue models, with most challenges stemming from socio-organizational rather than technical limitations (Potting et al., 2017). Open innovation strategies introduce coordination costs and control challenges, particularly in complex circular supply chains, where ensuring customer acceptance and long-term economic viability requires significant reconfiguration.

A study by Ranta et al. (2018) highlights that institutional drivers and barriers to CE vary significantly across different regions, including China, the United States, and Europe. In China, there is strong high-level regulatory support for CE initiatives, but implementation and enforcement at the local level remain weak. A distinguishing feature of the Chinese context is the informal recycling sector, which, while providing livelihoods for many, undermines the efficiency of formal recycling systems. This sector, composed of thousands of informal scavengers, removes valuable recyclables from waste streams before formal processes can access them, thereby depleting the input materials and reducing the viability of formal systems (ibid). In the United States, the absence of national-level CE regulations creates a barrier, despite normative support for recycling. Limited source separation and high processing costs further complicate efforts. Europe, by contrast, exhibits the strongest alignment between high-level directives and concrete regulatory measures, supported by a culture that encourages source separation and values the utilization of waste. However, across all contexts, institutional support continues to prioritize recycling over other CE strategies, such as reuse and reduction (ibid).

An overemphasis on recycling can inadvertently hinder broader CE principles by marginalizing reduction and reuse strategies. Institutional mechanisms such as certifications, subsidies, and regulations tend to favor recycling while offering minimal support for more upstream strategies (Ranta et al., 2018). This institutional bias constrains innovation efforts to the development of recycling technologies and limits systemic transformations needed for sustainable resource management. Normative societal values further reinforce this focus, rewarding recycling success while neglecting reduction and reuse initiatives. Additionally, cultural-cognitive barriers — such as consumer preferences for new products — continue to inhibit the development of reuse models (Ranta et al., 2018). As a result, a recycling-centric model narrows the scope of transformation envisioned by the circular economy.

Furthermore, implementing CE requires specific technological expertise and understanding, which may be lacking within organizations. Companies can struggle with the necessary know-how to redesign products for reuse, remanufacture, or effective recycling (Hussain et al., 2020). For some CE technologies (like advanced recycling or waste-to-energy), performance may be unpredictable and not always meet expectations, increasing investment risk (ibid).

2.1.3 Circular Principles and Practices

Despite extensive research on circular strategies and associated frameworks, there is no consensus on which principles or practices are currently being studied. This lack of agreement contributes to confusion among researchers and practitioners, making it challenging to understand how circular principles are implemented in practice. This thesis focuses specifically on digitally mediated circular practices. However, circular economy principles, practices, and strategies are often described interchangeably, with limited attention to the distinctions between these concepts.

The circular economy inherently involves material resource norms, which underscores the need for conceptual clarity in defining its guiding principles and practices. Earlier researchers of the circular economy described CE principles as the 3Rs — reduce, reuse, and recycle (Ghisellini et al., 2016). Although Ghisellini et al. (2016), introducing the 3Rs, referred to them as actions (p. 15), they continued to call them "principles," even though, arguably, they represent actions aimed at sustainable resource management. Reduce means minimizing resource and energy use during production and consumption to lower waste and environmental impact. Reuse involves using products or components again for the same purpose, extending their lifespan (e.g., repairing, sharing). Recycling refers to the reprocessing of waste into new materials for future use, thereby closing material loops. These definitions are widely shared among CE researchers (Bocken et al., 2016; Ghisellini et al., 2016; Henry et al., 2020; Korhonen et al., 2018; Zeiss et al., 2021).

Ghisellini et al. (2016) further offered three additional principles inspired by the Ellen MacArthur Foundation's three principles (EMF, 2013): design, reclassification of materials, and renewable energy. The first principle, *appropriate design*, emphasizes the importance of designing products for disassembly and reuse to avoid waste. The second introduces the reclassification of materials into *technical nutrients* (e.g., metals, plastics) and *biological nutrients* (generally non-toxic and biodegradable), with the former designed for reuse and the latter for safe reintegration into natural systems. The third principle, *renewability*, emphasizes the need for renewable energy to reduce fossil fuel dependence and increase system resilience to energy-related risks.

The table below (Table 1) illustrates the ambiguity in current studies regarding how different researchers define similar R frameworks. Although this ambiguity can be confusing, it also introduces *interpretive flexibility* (Bijker, 1995), which allows businesses to tailor practices to their context but may also create tensions in ecosystem collaborations.

Some researchers contextualize the 3Rs within organizational and environmental practices, such as Environmental-oriented Supply Chain Cooperation (ESCC). Zhu et al. (2010), for example, refer to circular economy practices as environmental protection requirements focused on reduction, reuse, and recycling. They argue that these 3Rs can positively influence both environmental and economic performance. ESCC practices include Green Purchasing (GP) on the input side and Customer Cooperation (CC) with environmental concerns on the output side, emphasizing the role of collaboration in preserving environmental value.

Likewise, agricultural practices in traditional table-olive groves have been recognized as contributing to CE. Martínez et al. (2024) identified 59 circular practices throughout the olive cultivation life cycle, involving the reduction of chemical inputs, the reuse of organic materials, and the recycling of resources. Practices such as maintaining plant cover, using organic fertilizers, and sharing machinery demonstrate how farmers engage in circular activities aligned with CE principles. These not only enhance environmental resilience but also improve economic viability, showing how traditional agriculture can model the implementation of CE principles.

These studies highlight disparities in how circular economy principles are conceptualized, further reflecting interpretive flexibility.

Table 1: Interpretations of circular economy principles and practices

Reference	**Principle**	**Practices**	**Strategies**
(Ghisellini et al., 2016)	Reuse, reduce, recycle, design, reclassification of material into technical and material nutrients and renewable energy		
(De Pascale et al., 2023)	Recycling, reusing and reducing		
(Cardenas et al., 2024)		Prevention, minimization, reuse, recycling, recovery, disposal	
(Martínez et al., 2024)		Reduce, reuse, repair, repurpose, recycle, recover	

(Urbinati et al., 2017)		Redistribution and reuse, remanufacturing or recycling of products	
(Blomsma et al., 2019)			Recover, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse
(Potting et al., 2017)			R0: recover, R1: recycle, R2: repurpose, R3: remanufacture, R4: refurbish, R5: repair, R6: reuse, R7: reduce, R8: rethink, R9: refuse
Ellen MacArthur Foundation	Eliminate waste and pollution, circulate products and materials (at their highest value), regenerate nature		
ISO standard (ISO 59004:2024)	Systemic thinking, resource stewardship, resilience, value creation		

For the purposes of this thesis, I define circular principles, practices, and strategies as follows. The Oxford Dictionary defines a principle as a fundamental truth or law — a motive force. Principles can thus be understood as fundamental values or doctrines that justify decisions and behaviors. Based on this definition and drawing on the ISO 59004:2024 standard and the concept of product stewardship (Hart, 1995), I propose that *resource stewardship* is a fitting principle for the circular economy. Acting as stewards of resources encourages the design out of waste, the regeneration of nature, and the closing of material loops. Such principles can then guide strategic and structural decisions to slow, close, or narrow loops, and to enact actions such as recycling, reusing, and reducing. While it is possible to recycle a resource, the motivation may not always be driven by resource stewardship — it may simply be a matter of necessity. For example, Derks et al. (2024) investigated the emergence of a circular e-waste ecosystem, where actors collected and recycled e-waste for economic reasons, primarily driven by necessity and the absence of regulatory constraints. Without the guiding principle of resource stewardship, such practices may cease once the economic need disappears. Thus, recycling, reusing, and reducing are actions that can be part of circular practices, but the principles guiding them, such as resource stewardship, are what truly make them circular.

The term "practice" can carry multiple meanings; it is sometimes used as the opposite of theory, or as a reference to the technical activities carried out by professionals (Czarniawska, 2015). However, practice theorists conceptualize practices as "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" (Schatzki, 2001, p. 2). To the best of my knowledge, R-strategies such as recycling, reusing, remanufacturing, and reducing can be practices when they involve materially mediated arrays of human activity that are organized around shared practical understanding.

Regarding circular strategies in this thesis, I will refer to them as R-strategies since an explanation is beyond the scope of this study. Although many researchers endorse these R-strategies (Blomsma et al., 2019), I argue that this list does not constitute a definition of strategy per se. Instead, these actions represent components of broader resource strategic efforts aimed at closing material loops and achieving organizational goals within a circular economy framework. Observations of organizational activities related to their circular strategies could provide more insights into the circular practices enacted. Limited research has explicitly explored circular economy practices, leaving conceptual and empirical gaps that this thesis seeks to address.

In the next section, I explain the approaches of digital technologies to enabling the circular economy, discuss the limitations, and introduce the theoretical lens.

2.2 The promise of digital technologies in the circular economy implementation

Digital technologies are increasingly regarded as key enablers in the implementation of CE strategies, offering new avenues for circular value creation. The academic discourse has examined this promise from various perspectives, including single organizational, and ecosystem-level and others remain conceptual, with each revealing distinct affordances and limitations of digital tools such as the Internet of Things (IoT), blockchain, mobile applications, digital platforms, and additive manufacturing.

Digital technologies have also been integrated into system-level frameworks (Ranjbari et al., 2024). For example, Ranjbari et al., (2024) developed a system dynamics simulation model for the food-sharing platform TGTG. Their model predicts that the platform could reduce food waste in Italy by approximately 3% by 2060, demonstrating the long-term potential of digital platforms to address systemic sustainability challenges. In the automotive sector, Turner et al. (2022) proposed a framework for aligning digital tools with maintenance practices, leveraging Industry 4.0 capabilities to enhance circularity and extend product lifespans. These cases illustrate how digital interventions, when aligned with existing practices, can advance CE objectives, albeit abstracting the complex dynamic of the interventions, and how maintenance activities are intertwined with Industry 4.0 technologies.

In Innovation Studies, green servitization also supports the view that digital integration enhances organizational learning and adaptability. Upadhayay et al. (2024) found that organizations combining digital and green strategies tend to be more innovative than those that do not. Likewise, Chaudhuri et al. (2023) showed that environmental dynamism and product-service innovation capability moderate the effect of green supply chain technologies on organizational performance. However, their research adopts a largely deterministic view of technology's influence on the green supply chain, focusing on outcomes without critically examining how technologies evolve in use or how they may reshape organizational structures.

Information Systems (IS) researchers who paid close attention to distinct types of circular strategies also noted that *implementation of the 3Rs framework (reduce, reuse, and recycle) varies based on complexity (Ranta et al., 2021; Zeiss et al., 2021). Among the three, reduce is typically regarded as the least complex, as it can often be implemented by a single organization with adequate digital infrastructure (Zeiss et al., 2021), for example a manufacturing company, utilizing Industry 4.0 technologies such as data analytics and automation to decrease energy consumption and material waste (Bag, Dhamija, et al., 2021; Bag, Gupta et al., 2021; Gupta et al., 2019). Reuse and recycling strategies, on the other hand, are more complex due to the need for the involvement of numerous actors and unclear boundaries in material flows, stakeholders, and processes (Zeiss et al., 2021). Approaching such complexity might mean adopting an ecosystem approach with diverse actor organizations to implement the circular strategy.

Understanding these interdependencies is, therefore, critical for the effective implementation of CE strategies, as it clarifies that it is not a deterministic and technocentric application, but rather a complex interaction between diverse social actors and physical and digital materials. In addition to the chosen circular strategy, the R strategies often have implications for the people involved and digital technology. However, little research has investigated how these complex dynamics among diverse actors, digital and physical material, unfold and are enacted in digital-mediated circular practice.

The above digital modeling, frameworks and conceptual works acknowledge a gap: much research has focused on theorizing or technical system design, with fewer empirical, practice-based studies detailing how circular R strategies such as reuse and recycle actually unfold with digital tools in organizational contexts. However, some studies are emerging. These tend to investigate platforms and ecosystemic implementation of digital technologies for specific circular goals or strategies.

At the ecosystem level, Additive Manufacturing (AM) serves as a prominent example of digital innovation supporting circular goals, ensuring the products printed can be reground after their end of life and printed again, and the product can be printed from recycled waste material. Rose & Bharadwaj (2023) introduced the “take-make-transmigrate” model, which extends beyond the traditional linear production paradigm. This model positions AM as a tool for reclaiming, repurposing, and reincorporating spent materials, thus reducing waste and enabling iterative innovation. Furthermore, it reveals how the team transforms product design strategies that support disassembly and account for material degradation, thereby fostering sustainability throughout the product lifecycle.

Other studies adopt an organizational and socially embedded view of digital technologies within CE contexts ; in other words, how the digital platform enables circular goals and what it offers social actors seeking to reuse, recycle, or resell used products and materials. For example, Blackburn et al. (2023b) explored how meta-organizations orchestrate digital platforms as novel organizational forms that facilitate circular value creation. These platforms reconfigure economic and technological architectures by enabling interactions among diverse actors. Their study identifies several platform-based business models, such as connecting vegetable producers with food manufacturers to close material loops, enabling the exchange of excess industrial resources to narrow loops, and providing platform-as-a-service models to support regenerative strategies (ibid).

Similarly, Ciulli et al. (2020) examined digital circular food platforms as “circular brokers” that bridge resource exchange gaps, referred to as “circular holes.” These brokers perform a variety of digital functions — including connecting (enabling new connections), informing (educating platform users about waste), protecting providers and users of waste, measuring impact, and integrating existing technologies — to support CE strategies. In another example, mobile applications such as *Rapel* enhance the economic value of recycled waste, thereby incentivizing waste reduction (Kurniawan et al., 2022).

However, the digital-mediated circular economy is not without its challenges. Adelekan & Sharmina (2024) observed that in the UK plastics sector, collaborative, digitally enabled circular business models aimed to enhance traceability, data sharing, and transparency throughout the plastics supply chain. The tensions arose around investment costs, access to data, and data governance. Tagging technologies for improved identification and sorting of materials proved challenging for food-grade polypropylene. Effective collaboration depends on stakeholders aligning incentives, sharing investment burdens, and agreeing on data management protocols to maximize mutual benefits and resolve emerging conflicts (Adelekan & Sharmina, 2024).

Collectively, these studies highlight multiple ways in which digital technologies contribute to circular value creation, whether through technological mediation, social reconfiguration, or their combined effects. Yet, apart from studies that examine design processes such as Adelekan & Sharmina (2024) and Rose & Bharadwaj (2023), who give some level of fragmented insights, the complex interaction of social, technical, and material elements in digitally enabled circular initiatives remains open. Less attention has been paid to how the dynamics of physical materials, technological selection, innovation, and social system influence each other to enact digitally mediated circular practices, and how circular principles inform and shape these practices.

2.3 Digitally Mediated Circular economy, Sociotechnical and Sociomateriality practice

Information Systems (IS) are inherently sociotechnical (Leonardi, 2012) and sociomaterial (Orlikowski & Scott, 2008), combining social and technical aspects, and therefore conceptually can be ahead of purely social or material fields in impacting research and practice for supporting a multidimensional circular economy. Sociomateriality research posits that the social cannot be separated from the material in the process of enacting a digital practice (Orlikowski, 2007; Orlikowski & Scott, 2008), while the sociotechnical approach posits that the social and technical systems influence one another, yet can be analytically separated (Leonardi, 2012).

Sociotechnical systems can be illustrated with a hospital that adopts a new electronic medical record (EMR) system: the technical aspect involves the software and hardware, while the social aspect includes doctors' routines and communication patterns. Researchers might analyze how doctors adapt their workflows (social) to the features of the EMR system (technical), treating each as a distinct but interconnected element. Sociomaterial practice or sociomateriality can also be illustrated with an architect using Building Information Modelling (BIM) software. In this approach, the social (the architect's knowledge and decisions) and the material (the BIM system and design constraints) are seen as inseparable — design work emerges from their ongoing mutual entanglement within practice, not as separate influences.

Regarding digitally mediated circular practices, the sociomateriality lens I propose is plausible. However, there is still one aspect missing in current studies: the materiality of physical materials, and more specifically, the waste material and the circular principle of resource stewardship. I argue that enabling the circular economy with digital technologies is in line with sociomateriality, that is, it is also not a deterministic or technocentric approach. There is a social aspect that needs to be considered (Moreau et al., 2017), a sociomateriality (Orlikowski & Scott, 2008), and a material aspect (Alkki et al., 2024). The material is not only digital technologies conceptualized as material in the IS field (Leonardi, 2010, 2012) but also physical materials. This adds a layer of complexity to sociomateriality practices in digitally mediated circular economies. As it encompasses both physical and digital materials, digitally mediated circular practices need to address physical materiality (agency), including waste materials; more on this in the next chapter.

The digitally mediated circular economy encompasses the social and two types of materials: digital and physical. The *social* includes organizational structures, people, strategies, and the alignment of actors, whereas the *digital materials* consist of IT infrastructures (hardware and software) (Balloni et al., 2012; Leonardi, 2012), and *physical materials* include physical waste, products, and used products (Alkki et al., 2024; Leonardi, 2010).

The **social (hereafter human)** dimension inherently involves the *transitioning* of organizational practices towards circularity (Geissdoerfer et al., 2017; Kanda et al., 2021). However, this transition is not straightforward, especially for established businesses. Circular transitions require systemic collaboration, compelling businesses to identify and engage partners, often outside their existing networks, in interdependent activities (Geissdoerfer et al., 2023; Kanda et al., 2021). Moreover, both consumers and incumbents often exhibit hesitation or lack awareness, which further impedes the adoption of circular practices (Kirchherr et al., 2018). New entrants developing circular business models face an additional set of constraints.

In addition to the typical liabilities of newness and small size encountered by most startups (Gimenez-Fernandez et al., 2020), circular entrepreneurs (Henry et al., 2023) confront unique challenges.

The **digital and physical material** combined present tightly linked challenges that demand simultaneous attention. For example, there may be an unavailability of suitable waste materials, a high dependency on external stakeholders, and a lack of data, technical, and material knowledge required to develop durable products (Geissdoerfer et al., 2023; Kanda et al., 2024; Vermunt et al., 2019). Furthermore, specific circular business models face particular issues; for example, recycling marketplaces often struggle to secure upfront financial capital, while businesses focusing on repurposing and upcycling deal with a lack of data and uncertainties in the quality and quantity of waste material inputs from waste owners, such as waste management companies and municipalities (Kanda et al., 2024). These uncertainties can hinder scalability, even when the waste material itself is inexpensive or freely available.

Circular practices rely on material-, actor-, and location-related data (Zeiss, 2019). When such data is absent or unreliable, transaction and operational costs rise as organizations spend more resources searching for and validating information (Zeiss, 2019). For example, the UK's One Bin System collaborative advocated for an open dataset to address fragmented, siloed, and untraceable plastics data (Adelekan & Sharmina, 2024). While designed to enhance transparency and collaboration, the initiative faced data governance challenges, including disputes over ownership, equitable access, and protection of proprietary information (Abraham et al., 2019; Khatri & Brown, 2010). Developing a governance model that balances open access, security, and fair value distribution remains a critical barrier.

These challenges are closely linked to gaps in digitally enabled circular practices. Many datasets do not meet circular economy requirements, and data on physical material flows is often scarce or fragmented due to the absence of such practices. Although Jarvenpaa and Essén (2023) did not study the circular economy directly, their notion of data sustainability is highly relevant here. They highlight these relevant challenges: data may remain locked into old socio-technical regimes and be unable to transfer to new ones, or it may fail to become embedded in and translated within the social and material networks needed to support new practices. Such lock-ins effectively sustain practice voids, as data tied to outdated systems cannot enable the emergence of digitally mediated circular practices.

The EU's push for a product passport (data.europa.eu, 2024) underscores the urgency of addressing these gaps (Walden et al., 2021). Yet, the convergence of digital technologies and the circular economy is nascent and does not yet generate the kind of reliable, interoperable data needed. This shortage of usable data both creates *data voids* and prevents the development of new *digitally mediated circular practices*, leaving practice voids unfilled.

Consequently, establishing digitally mediated circular practices marks a significant shift in how business-as-usual practices are conceived and implemented. While previous research has emphasized the importance of the social system — covering creation, governance, expansion, and value accumulation (Blackburn et al., 2023) — and has examined the financial, organizational, and institutional challenges faced by circular startups (Kanda et al., 2024; Moreau et al., 2017), as well as the role of digital technologies (Bag, Dhamija, et al., 2021; Bag, Gupta et al., 2021; Ranjbari et al., 2024; Zeiss et al., 2021) and data (Hoppe et al., 2025; Turner et al., 2022; Zeiss, 2019) in influencing the circular economy, the emergence of digitally mediated circular practices through the interaction of these dimensions remains underexplored.

To this end, I argue that human-material dimensions in circular ecosystems are uniquely complicated due to their explicit commitment to circular economy principles and the sustainable management of tangible material resources. To emphasize, when circular economy principles drive digital innovation, this brings attention to physical materials and their characteristic in the digital innovation (Yoo et al., 2012), and specifically in digital functions such reprogrammability, traceability, storage (Yoo, 2010; Yoo et al., 2010), which are chosen to support the circular strategy, such as reuse, recycle, and recycling. For example, a deeper analysis of Rose & Bharadwaj's (2023) study mentioned above reveals a circular type of 3D printing project that aimed to shift away from the traditional, wasteful "take-make-dispose" production model and replace it with a more sustainable, circular "take-make-transmigrate" approach. This new model utilizes additive manufacturing (AM) to enable material reuse, reduce environmental impact, and support a circular economy. The 3D-printed chair, known as the Murex chair, was specifically designed to demonstrate the potential for reusing AM polymers. First, the chair was printed using recycled ABS polymer sourced from spent 3D-printed automobile chassis, showcasing material reclamation. After printing, the full-size Murex chair prototype was intentionally ground down and pelletized as proof of closing the loop from virgin polymer to a spent automotive part, to furniture, and back to raw polymer materials. The design emphasized both the use of recycled input material (attention to physical materials) and its complete recyclability (following circular principles), proving that AM polymers can be reused across multiple product generations without significant loss of quality or structural integrity. This demonstrates that additional complexity is placed on designers and engineers when designing for a circular economy, requiring attention to the physical material and relationships to enable the ongoing sociotechnical digital innovation cycle.

In a similar vein, Adelekan & Sharmina (2024) also showcased the collaborative, whose main aim was to design digitally mediated circular business models that retain material value, improve recycling efficiency, and create shared economic, social, and environmental benefits for all stakeholders. The primary problem with the tagging technology was its limited ability to distinguish food-grade from non-food-grade polypropylene (PP). While near-infrared (NIR) sorting systems could identify polymers, they could not identify whether PP was safe for food packaging, which is crucial for closed-loop recycling. To align the tagging process with circular principles, stakeholders focused on enhancing the digital capabilities to sort and recycle plastics, particularly food-grade polypropylene (PP). They introduced additional identification to tagging technologies, such as marking the food-grade PP with fluorescent inks applied during packaging manufacturing. They retrofitted sorting facilities with ultraviolet (UV) light sources to distinguish food grade from non-food grade PP. Additionally, they considered using QR codes or Radio Frequency Identification (RFID) tags applied directly to packaging to enable traceability and provide item-level data across the supply chain. These digital innovations improved identification accuracy and supported closed-loop recycling. The examples demonstrate the need for significant retrofitting of physical products and materials to redesign the digital innovation process, ensuring the circular principles of resource stewardship.

2.4 Extension of the Mangle of Practice Lens

These studies also reveal the multiplicity of agency from social and human actors, as well as physical and digital non-human actors. Agency used to be only ascribed to humans but now materials also have agency, referred to as materiality (Leonardi, 2010, 2012). However, human and material agency play out differently; human agency carries intentions and purpose, while non-human agency, the digital and physical, responds to human action and is "temporarily emergent in practice" as the agencies reciprocate their agency during their use (Pickering, 1993, p. 564). As Andrew Pickering (1993, p. 564) eloquently explained, "*the contours of material agency are never decisively known in advance; scientists continually have to explore them in their work, problems always arise and have to be solved in the development* *of, say, new machines. And such solutions - if they are found at all - take the form, at a minimum, of a kind of delicate material positioning or tuning, where I use 'tuning' in the sense of tuning a radio set or car engine, with the caveat that the character of the 'signal' is not known in advance in scientific research.*"

Notably, the reciprocal agency between human and non-human actors (including digital and physical) complicates the digitally mediated circular economy more than non-circular, digitally focused innovation. Yet current studies overlook the physical material and their agency in the process and focus solely on digital material agency. They offer only a fragmented understanding of how these circular principles and sustainability goals are *enacted* in digitally mediated circular innovation. Therefore, research is needed to illuminate how CE principles — such as resource stewardship, waste prevention, and circular material flows — are embedded and performed through human-materials agency. Non-human materials play a role, with their own peculiar agency reflected in their resistance to human accommodation. This dialectic process produces emergent results.

In this thesis, I extend Pickering's mangle of practice (Pickering, 1993) to the circular economy context. It has been successfully applied in both digital and non-digital contexts (e.g., Barrett et al., 2012; Eaton et al., 2015), and it equips me with the analytical lens to observe material and non-material agency in developing digitally mediated circular practices that unfold within the circular ecosystem.

Pickering introduced the concept of tuning within the mangle of practice to describe how human and material agencies are adjusted and coordinated during scientific and technological work. Tuning is not entirely predictable, but rather involves continuous negotiation between *accommodation* and *resistance*. Scientists and engineers may attempt to impose their intentions on material entities, but when faced with resistance, they must adapt by accommodating or adjusting their methods. If accommodation is insufficient to overcome resistance, certain strategies or assumptions may be abandoned altogether. This dynamic process underlines Pickering's view that scientific and technological development is not linear or purely rational, but contingent and emergent (Bijker, 1995), shaped by ongoing interactions between human and material agencies.

This tuning concept has been applied in various domains, including the embeddedness of robotic technology in the pharmaceutical industry (Barrett et al., 2012) and the evolution of digital platform ecosystems (Eaton et al., 2015). In these contexts, **tuning** helps explain the dialectics between human and non-human material elements in both the innovation process and its use. Barrett et al. (2012) extended the tuning concept to show how digital technologies reshape organizational boundaries in complex, multi-occupational settings. They demonstrated how digital and physical materialities interplay in shaping work dynamics. Eaton et al. (2015) highlighted distributed tuning across platform owners, complementors, and users, demonstrating how boundary resources — such as APIs and SDKs — are iteratively adjusted through collaborative negotiation. These examples provide insight into how ecosystems evolve through multi-stakeholder interactions.

However, to the best of my knowledge, the concept of tuning has to date not been applied within the context of the digitally mediated circular economy, nor has the impact of such systemic constraints on tuning processes been explored. Therefore, I argue that the tuning lens can be applied in my research to enable me to fulfill my research aim of understanding how digitally mediated circular practices are enacted in emerging ecosystems confronted with practice voids.

3 Methodology

3.1 Ontological and Epistemological position

My ontological philosophy of science aligns with a subjectivist or social constructionist view. This means that reality is understood as socially constructed through human cognition and interaction. Reality is also not static or external but continuously created through the dynamic relation with the individual and their environment (Burrell & Morgan, 1979). This contrasts with the realist objective view, which posits that reality is hard, real, and external to the individual (Burrell & Morgan, 1979).

This ontological position informs my epistemological orientation, which is interpretivist in nature. Given my view of the world as socially constructed, I adopt an interpretive approach to knowledge generation, primarily through qualitative methods. I aimed to understand the phenomenon under study by engaging with social actors (e.g., through interviews), eliciting their interpretations of their actions, and combining these insights with my own observations. This enables me to understand how a particular reality is constructed and how it may inform, extend, or challenge existing theoretical frameworks. Information systems research, in general, and in my subjective area, where I link the circular economy context to information, has been dominated by a deterministic positive view of digital technologies enabling a circular economy.

Interpretivist and social constructionist philosophies challenge the deterministic view common in studies of my phenomenon of interest. Therefore, my approach to generating knowledge is to be as close as possible to the study subject, aiming to understand and gather detailed insights and stories from the informants.

3.2 Research Design

To construct the reality of the digitally mediated circular economy based on a subjective epistemology, I employ a qualitative case study design, which allows for an in-depth exploration of dynamics, processes, and situated practices within a real-world context, typically within one or multiple organizations or systems (Eisenhardt, 1989). The qualitative case study is in line with the interpretivist philosophy to enable my subjects under study to unfold their *"nature and characteristics during the process of investigation"* (Burrell & Morgan, 1979, p. 6).

In this thesis, I studied and compared two cases, enabling me to examine both unique characteristics and shared patterns. I draw on the comparative case study approach as outlined by Yin (2014) and Eisenhardt (1989). This methodology supports an in-depth, context-sensitive investigation of complex, real-world phenomena. This comparative approach offers a deeper understanding of how digitally mediated circular practices are enacted and how the interplay between digital technologies, waste material properties, and the principles of the circular economy influences them. It follows Yin's replication logic, treating each case as a distinct experiment to understand how material agency, human intentions, and situated negotiations interact in the formation of circular practices.

3.3 Case selection

I started my research on the role of digital technologies in the circular economy. In 2019, when I began my journey, circular economy research was in its early stages; there were more reviews and conceptual papers than real-world application cases. Almost all the earlier circular economy researchers (e.g., Brown et al., 2019; Geissdoerfer et al., 2017) agreed that enabling the circular economy is a collaborative and systemic effort. My research, therefore, focused on understanding how inter-organizational collaboration enables the digitally mediated circular economy and how it facilitates collaboration with others. Essentially, the aim was to explore how inter-organizations organize a digitally mediated circular economy.

At that time, I stumbled upon the ecosystem concept, which characterizes types of inter-organizational collaboration that jointly materialize a value proposition (Adner, 2017; Gawer & Cusumano, 2014; Jacobides et al., 2018; Moore, 1993). These ecosystem studies were mostly in the fields of Strategic Management and Information Systems, which influenced my understanding of the ecosystem and how it is conceptualized in both studies. Later in my journey, other research positioned circular ecosystems in the ecosystems discourse to develop the circular economy in both strategic management (Aarikka-Stenroos et al., 2021; Kanda et al., 2021; Ranta et al., 2021) and information systems (Zeiss et al., 2021). These developments helped me to establish my object of interest and context clearly, as ecosystem organizations, and my unit of analysis was the digitally mediated practice.

I adopted a purposive sampling strategy rooted in theoretical and polar case criteria as outlined for rigorous case research (Voss et al., 2002). Specifically, my goal was to select cases that represent ecosystem contexts in which organizations are demonstrably committed to using digital technologies for waste recovery, operating under the circular principles and strategies of recovery, recycling, and reuse to generate new products. To this end, I identified two ecosystems meeting these criteria — one located in Ghana, Africa, and the other in Portugal and Sweden, Europe.

These cases were chosen not only because both ecosystems are deeply invested in circular economy practices mediated by digital technologies, but also because they present contrasting geographic and operational contexts. By selecting cases that share a similar ideological commitment yet differ in their technological approaches and processes to waste recovery, I employed a "polar types" sampling logic (Voss et al., 2002). This approach is recommended for highlighting contrasting characteristics to deepen understanding of how similar phenomena manifest in diverse environments. It is helpful in exploring the boundaries of the conceptual constructs being investigated (Miles et al., 2014).

The sampling rationale was further strengthened by seeking both similarities and differences across the two cases. This comparative dimension enabled me to examine whether underlying mechanisms mediating circular economy transformations through digital technologies are consistent across different contexts, or whether key factors are context dependent. Such cross-case comparison is critical in theory-building case research, as it aligns with best practices in case research, where a focused yet contrasting sample allows the researcher to uncover patterns, refine constructs, and develop empirical foundations for new theoretical insights (Voss et al., 2002; Yin, 2014). Additionally, including organizations from distinct geographic regions increases the external validity of the research and provides a foundation to assess the generalizability of emergent findings across different environments.

3.3.1 Case Study A - The Ghana Waste Recovery Platform - Africa

The Ghana Waste Recovery Platform (GhanaWaste hereafter), orchestrated by the United Nations Development Program (UNDP), was an appropriate choice for study as an example of a circular economy ecosystem addressing the plastic waste problem on land and in the ocean through a digitally mediated circular economy platform in Ghana. GhanaWaste was established in 2018; however, I began collecting data during two periods: from April to May 2022 and in January 2024. The platform consists of (a) local entrepreneurs who mobilize local citizens and waste recovery and recycling businesses to participate in their ventures, (b) local and international non-governmental environmental and other organizations, e.g., churches, mosques, (c) development partners, (d) national and international researchers, and (e) local and international government agencies to promote waste recovery and support the circular economy. The platform was established with seed funding of USD 500,000 from UNDP's Country Investment Facility. It employs both physical meeting activities (e.g., business capacity workshops, beach clean-ups) and a digital platform that provides information and facilitates plastic material exchange (e.g., entrepreneurs input data on plastic resource collection, use, and treatment activities, and provide and update their contact and location information).

GhanaWaste has over 300 active actors from numerous public, non-profit, and private organizations in Ghana. Today, Ghana produces about 800,000 tons of municipal waste annually (NPAP Ghana, 2021), and a report from the Ghana National Plastic Action Partnership (2021) revealed that the country has a plastic waste collection rate of 49%. However, only 25% of the plastic waste collected is properly managed. Of the remaining 75%, 26% is dumped on land, 23% is left at uncontrolled dumpsites, 17% is openly burned, and 9% leaks into local water bodies. Further, unless immediate action is taken plastic leakage into Ghana's water bodies is expected to increase by 190% from 2020 to 2040, rising from approximately 78,000 to 228,000 tons annually (NPAP Ghana, 2021), which would have a detrimental impact on marine life and livelihood for the country's many coastal communities.

Ghana is committed to establishing a local recycling industry that protects the environment and supports the socio-economic well-being of waste pickers, who are predominantly impoverished and often female. There have been several attempts to use digital innovation to help support the waste recovery effort in Ghana. Initiatives include the Global Plastic Action Partnership (GPAP) through the Plastic Action Initiative Tracker (2022) and the plastic traceability project by SAP and the Ministry of Environment, Science, Technology & Innovation (MESTI), which is aimed at reducing plastic waste (SAP News Center, n.d.). These efforts have helped organize waste pickers more effectively, incentivizing them and increasing the value of plastic waste.

However, these efforts have not had any significant impact. What was needed was a collective action involving all stakeholders in the waste recovery sector – the ambition of GhanaWaste. GhanaWaste brought together approximately 500 diverse stakeholders, ranging from individual companies operating independently to solve environmental waste challenges to non-governmental institutions, entrepreneurs, public organizations, and information technology firms. Prior to the initiation of GhanaWaste, these stakeholders worked in isolation or in partnership with only a few others. Most stakeholders did not have a website, only a handful had Facebook pages, and some could not be found on Google's search engine or Google Maps. Moreover, most did not have digital record-keeping procedures, making it difficult to document their waste management activities. This initiative was the first attempt to fill the data gap and have a holistic view of waste management challenges.

Ghana can be considered an information-poor country, as most information and data are collected manually or stored on the local hard drives of many institutions. Additionally, Ghana's public statistics service releases data, including census and household data, every decade. The collection mode can be considered inaccurate as it comprises computer-assisted personal interviews. A critical problem is related to inadequate, absent, and untimely data, which adversely affects the pace of the economy's ability to become circular. In this research, we followed how GhanaWaste, a group of circular economy businesses, established a Data Commons platform to address data voids. From the curation of Data Commons, GhanaWaste also co-created digital innovation ideas and successfully developed an information website to fulfill the informational needs of all members, including a digital waste resource map that mapped over 100 waste collection and recycling points in Accra, the country's capital. The goal was to increase awareness and patronage of Ghana's existing circular economy businesses and to scale recycling and reuse practices. Figure 1 illustrates the waste management ecosystem, including its challenges and associated activities.

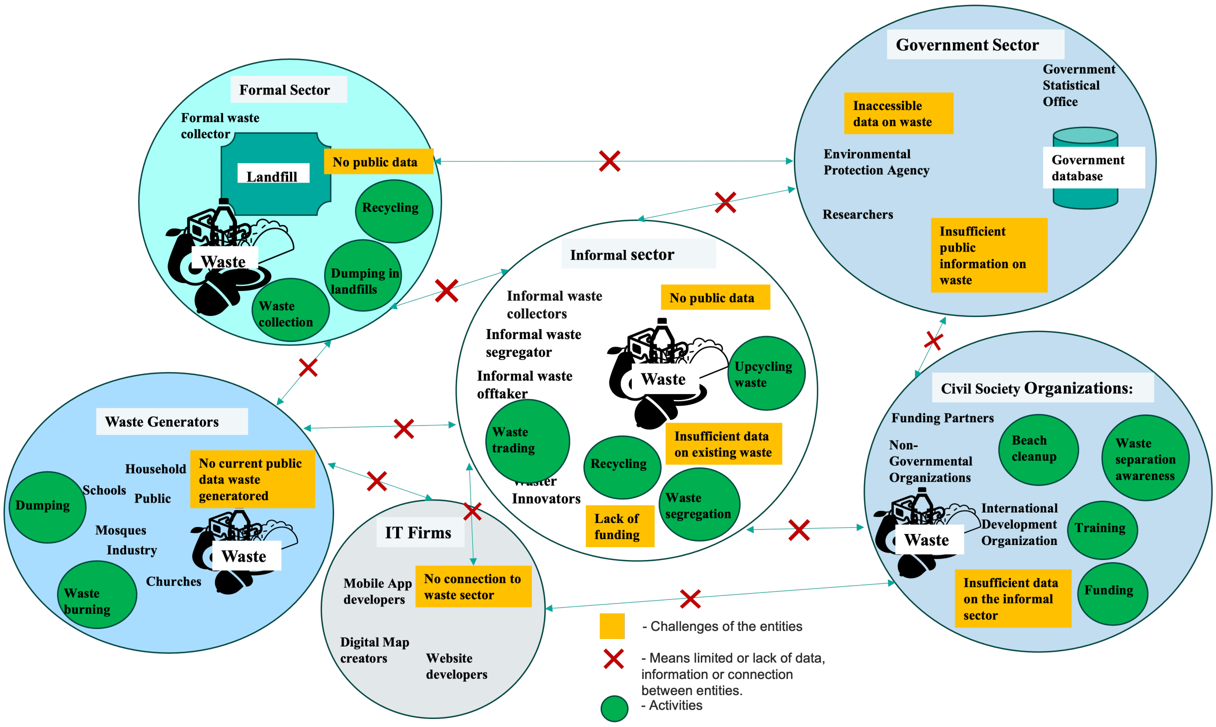

Figure 1 Ghana Waste Management Ecosystem

3.3.2 Case Study B: PlasticsOrg - Europe

PlasticsOrg originated in Peniche, Portugal, and later grew into an ecosystem of actors in Sweden and Portugal. It started with several circular entrepreneurs with the main goal of rejuvenating economic activities in Peniche through digitally mediated circular economy value creation. The envisioned digital technologies they intended to leverage included additive manufacturing (3D printing), blockchain, Artificial Intelligence (AI), and the Internet of Things (IoT). Studying PlasticsOrg's journey from its birth in Portugal to becoming a brainchild of the circular economy ecosystem aligns with my criteria for examining an ecosystem committed to utilizing digital technologies to facilitate the circular economy.

PlasticsOrg started up in June 2018 and has been in business since. This study focuses on the period from June 2018 to November 2024. PlasticsOrg initially started with a recycling unit that collected used fishing nets from the ports in Peniche, Portugal. The nets were cleaned and compounded into pellets intended for use in additive manufacturing or 3D printers to create valuable products (see Figure 2 for an illustration of the work steps).

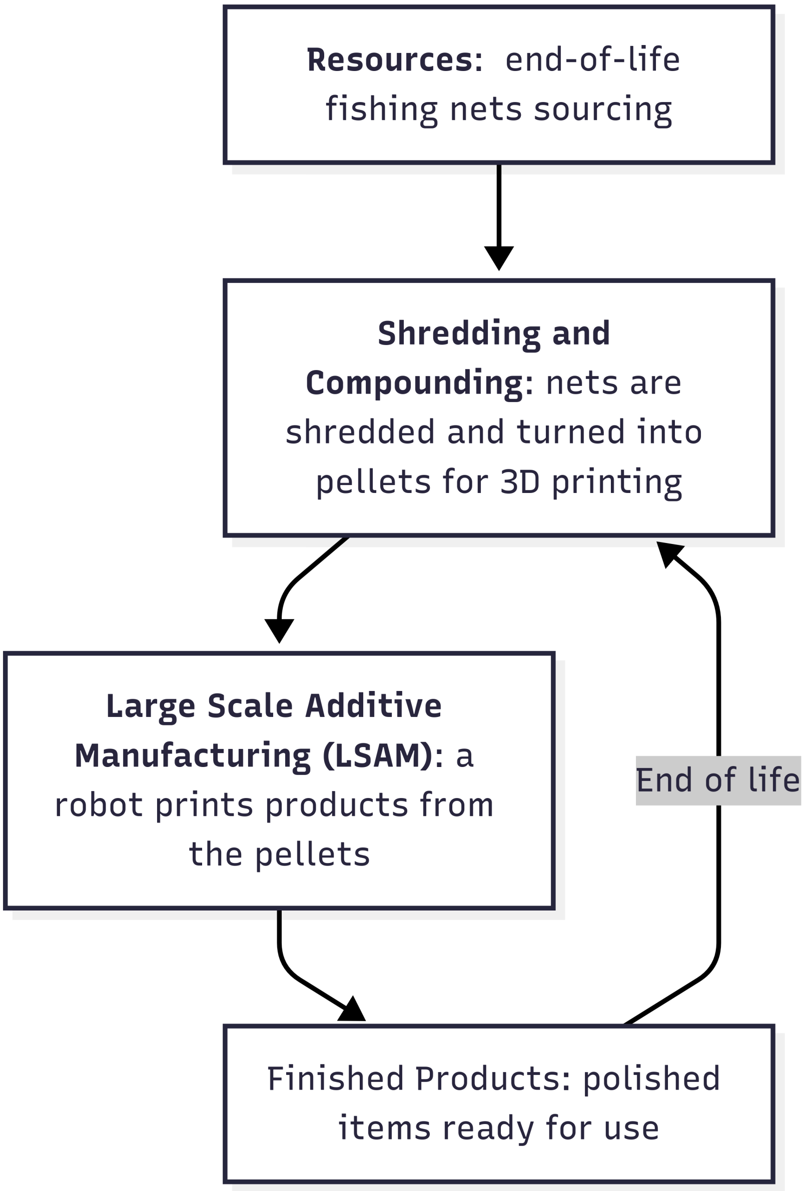

Figure 2 Additive Manufacturing process of the Circular Economy Ecosystem

Introduction of the case companies and their evolution. The first company created was OceanWasteHub, which was designed to mimic a Silicon Valley tech hub focused on the blue circular economy and innovations to remove discarded fishing nets from the ocean. They began by conducting the recycling process, which they called WasteCollect. However, after conducting research and ideation, they decided to establish another company in Sweden called BoatingOrg to sell the recycled material, which they later decided to use to print boat hulls or furniture for boating. Unfortunately, this did not work out as planned, so they created yet another company called 3DStudios to print high-end furniture from the compounded plastic derived from the discarded fishing nets.

Their experimenting and prototyping of 3D-printed chairs with high-end designs was successful. They were able to showcase their high-quality furniture in showrooms in Stockholm and Milan. The CEO of 3DStudios, who is a fashion expert, played a crucial role in determining the product's suitability for high-end consumers. 3DStudios generated media attention in reputable outlets such as *Vogue* and *Residence* magazines.

The entrepreneurs gathered and inspired many partners who were interested in joining their circular economy journey. In order to continue their operations and conduct advanced research, they successfully sought funding from InnovationFund, the government's innovation funding agency. This allowed them to conduct further research to explore how to advance their innovation and technology and scale their initiative with their partners. The project was named OceanAM and involved the formation of an ecosystem consisting of a number of companies whose aim was to manufacture 3D-printed high-quality furniture from recycled discarded fishing nets. The initial funding was for six months; they later received further funding of SEK 29 million which was to run from May 2023 to May 2026, to (1) implement a circular economy, large-scale additive manufacturing (LSAM) microfactory concept, (2) increase recycling of polymer waste materials into secondary raw materials for additive manufacturing, (3) reduce material, energy, and other resource usage through an optimized LSAM process, (4) extend the life products and production systems through LSAM of new components, and (5) facilitate the creation of an LSAM microfactory network.

3.4 Comparison between the two cases

Table 2 provides detailed comparison of the key elements in the two cases that further present contrasting geographic and operational contexts. The cases share a similar ideological commitment yet differ in their technological approaches to and processes of waste recovery.

Table 2 Comparing the elements of the two cases

Key elements	Case Study A: GhanaWaste	Case Study B: PlasticsOrg
Orchestration	Distributed	Distributed
Ecosystem process	From affiliated to structured	From a single firm's entrepreneurial initiative to a structured ecosystem
Location of the plastic waste	Ghana	Portugal-Sweden

Waste resources	Plastic bottles and packaging, and animal waste	Discarded fishing nets
Material	PPE, LDPE	PA6 Nylon
Digital technology	Digital platform, waste map, mobile waste exchange app, online directory	Large scale additive manufacturing 3D printing robot, computer simulations, 3D designing software, and robotic programming
Actors	Entrepreneurs, small to medium-size companies, large and established waste management firms, public organizations, researchers, NGOS	Entrepreneurs, startups, research institutes, established firms, researchers, Swedish firms
Ecosystem Leader	International development organization	Single circular business
Companies producing the product waste	Plastic bottling companies, plastic sachet packaging, and soft drinks companies	Fishing net manufacturers
Location of the companies producing the products that became waste	Ghana, China	China
Location of the digital technology	Online (accessible online)	3D printing technology (Sweden) Sales (online)
Owners of the residual resource	Many actors own their respective waste recovered by themselves	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 organization	Swedish Government Research Group, Ecosystem leader - Startup
Ownership of the digital technology	Rotating ownership	Distributed
Complementary Assets	Data, knowledge, residual resources, economic value, and funding	Residual resources, knowledge, and funding
Value creation	Upcycled residual resources into various products such as building blocks for construction, plant pots, plastic lumber, bus stop design, furniture	Remanufactured waste resources into high-end furniture, custom designs
Challenges - practice void	Lack of established practices, mismatch value systems for residual resources, material challenges connecting with experts. Data-related challenges: lack of data to enable exchange of materials,	Lack of established practice, mismatch of value systems for residual resources, material challenges connecting with experts, technological challenges with 3D printing, robots, programing and the 3D designs

	lack of data for monitoring and coordination, lack of data to represent the ecosystem activities	

3.5 Data Collection

3.5.1 Case A GhanaWaste (Papers 1 and 2).

I collected data using a combination of semi-structured interviews, document analysis, and observation. I conducted exploratory interviews during my stay in Sweden and subsequently traveled to Ghana to complete the interview process. In preparation for my trip to Ghana, I developed an interview guide that incorporated theoretical constructs related to data governance, data work, and ecosystems. I sent emails to request interview appointments. Please see the draft of the correspondence (Figure A1 in Appendix A) and the interview guide (Table A1 in Appendix B) provided below. Most interviewees preferred to conduct interviews via Zoom, as they had become accustomed to online interactions during the COVID-19 pandemic. They found this method to be more convenient, given that many were focused on their business activities.

I conducted 26 interviews to support the two studies, divided into two rounds (see Table 3). The first round was in Ghana, from April to May 2022; afterwards, I had several follow-up meetings when I returned to Sweden, in the form of engaged scholarship (Van De Ven, 2007). I held several meetings with interview subjects to receive feedback on my interpretations of their activities toward a digitally mediated circular economy. The second round of interviews was conducted in January 2024, and focused on detailed technical activities. The need for the second round emerged during data analysis when I realized that several technical activities were being carried out collaboratively to build a database addressing the data voids unique to their context. The activities were necessary for capturing waste-related, actor-related, and waste treatment activities. The interviews therefore focused on the technical experts who led the project.

Apart from the interviews, I had access to archival documents of internal reports and PowerPoint presentations from the initiative's inception. This provided me with a deeper understanding of their entire journey and helped me triangulate the data.

Table 3 Data Sources for GhanaWaste

Primary data				
ID	**Interviews of ecosystem actors**	**Number of people**	**Number of interviews**	**Duration of interview**
P1, P2	Pioneering team (Orchestrator)	2	P1 (2) P(1)	2 hrs 1 min
O1, O2	Development organization (Orchestrator)	2	O1(1) O2(2)	1hr 40 mins
GOV1	Public institution (Statistics)	1	GOV1(2)	54 mins
C1	Civil society organization	1	C1	44 mins
N1, N2, N3	Non-governmental organization	3	N1, N2, N3	3 hrs 20mins
WA1, WA2, WA3, WA4, WA5	Entrepreneur (Waste upcycling)	5	WA1, WA2, WA3, WA4, WA5	4 hrs 3 mins
WB1, WB2, WC3	Entrepreneur (Waste recovery and selling)	3	WB1, WB2, WC3	3 hrs
F1	Funding partner	1	F1	38 mins
B1	Business capacity building partner	1	B1	41 mins
IT1, IT12, IT13	IT businesses	3	IT1, IT12, IT13	3 hrs
Total		22	25	20 hrs 1min
	Informational Meetings	**Number of participants**	**Number**	**Duration**
	Online meeting observations	>200	3	6 hrs
Secondary data				
Internal Power Point meeting documents			10	>100 pages
Internal reports shared with actors			14	>100 pages

3.5.2 Case B PlasticsOrg (papers 3 and 4)

The data collected were qualitative and included semi-structured interviews, documents, and observations. Although PlasticsOrg started up in 2018, I began my formal study in November 2022. I had access to a significant amount of archival data, documented by a PlasticsOrg representative who is also my supervisor, as they intended to make it a case study. I created an interview guide to understand the journey and challenges of establishing a digitally mediated circular business (See the interview guide in Table B1 of Appendix B). I drafted an email to invite participants to schedule an interview time (see the email template in Figure B1 of Appendix B). The interviews, each lasting about one hour, were retrospective since much had occurred before I initiated the investigation. The first round of data collection took place between November 2022 and May 2023. The interviews were conducted on Zoom, except for one face-to-face interview at a research institute. I supplemented the interviews with notes from meetings and observations from Zoom meetings and on-site visits. I also drew on other data sources, such as documents generated during idea inception events, a TED talk about PlasticsOrg's vision, PowerPoint presentations, pitch decks, and social media posts of members and companies involved (e.g., LinkedIn, Facebook) to corroborate the timing of events, various activities, and trajectories of ideas and actions, in addition to emails and meeting notes obtained through PlasticsOrg.

The second round of data was collected by two master's students in early 2024, who interviewed the Plastics-LSAM team to also understand the orchestration mechanism of circular economy ecosystems that are developing futuristic ideas. In late 2024, I conducted additional interviews with the Plastics-LSAM team and made an on-site visit to observe the 3D printing process and take field notes. In all, we conducted 30 interviews, with several archival documents and three on-site observations (see Table 4).

Table 4 Data Sources for PlasticsOrg - Case B

Type	Aim	Number
1. 1st round of interviews	Retrospective accounts	14
2. 2nd round of interviews	Retrospective accounts	16
3. Interviews by media	Actors' circular motivation	6
4. Social media LinkedIn posts – Autumn 2020 to April 2023, Youtube (Ted talk), Slideshare	- Plans and outcomes - Event announcements - Ecosystem growth	50
5. Observations	Work environment	3
6. Meeting notes	Plans and activities	15
7. Archival materials	Vision, strategy, operations	>100
8. Emails and email threads	Conversations re plans, problems, actions, and outcomes (not systematically analyzed; author 3 identified specific emails as evidence after discussing analysis)	>1000

Data collected for both cases, GhanaWaste and PlasticsOrg, are summarized in Table 5. Interviews for the two studies totalled 55, that is 25 from GhanaWaste and 30 from PlasticsOrg.

Table 5 Data sources for GhanaWaste and PlasticsOrg

Type of Data	GhanaWaste	PlasticsOrg	Total
Interviews	25	30	55
Social Media Posts	NA	>50	>50
Meeting Notes	NA	>20	>20
Observations	3	3	6
Archival Documents	24	> 1000	>1024

4 Summary of Papers

In this section, I summarize the four appended papers. Table 6 highlights the main foci and my role in the papers.

Table 6 Summary of appended papers

Order	Title	Paper Focus	My role
Paper 1	Heathcote-Fumador, I.E. & Selander, L. (2025). Dealing with "Data Voids" in Emergent Circular Businesses. *European Conference on Information Systems (ECIS) 2025 Proceedings.*	Data and digitally mediated circular economy implementation. Data Commons creation to overcome data voids	Conceptual framing, data collection & analysis, formulating contributions, and general writing
Paper 2	Heathcote-Fumador, I.E., Cepa, K., & Teigland, R. (Under review). Ecosystem Data Governance: Aligning Data Governance and Ecosystem Orchestration to Address Grand Challenges. Manuscript under Peer Review at *Information & Organization*. Previous version published in *Academy of Management Proceedings*, 2025.	Ecosystem orchestration and data governance alignment to enable circular ecosystem monitoring and value creation	Conceptual framing, data collection & analysis, formulating contributions, and general writing
Paper 3	Heathcote-Fumador, I.E., Cepa, K., Teigland, R. 1.(Manuscript) Overcoming conflicting linear and circular logics: A process study of how rotating orchestration drives circular ecosystem emergence.To be submitted to *Organization & Environment*	Emergence and challenges of circular production systems	Conceptual framing, data collection & analysis, formulating contributions, and general writing
Paper 4	Heathcote-Fumador, I.E. (2025). Tuning Work as a Representation Mangle: Achieving Circular Production through Additive Manufacturing with Recycled Polymers.	Digital circular production implementation process through tuning lens, tuning as a	Everything from conceptualization to final paper

		representation mangle.	

4.1 Paper 1

Heathcote-Fumador, I.E. & Selander, L. (2025) Dealing With "Data Voids" in Emergent Circular Businesses.

The study was driven by the core research question: *How do circular economy businesses establish data commons to address data voids?* This question stems from the growing recognition that, while circular strategies — like recycling and reuse — require rich, accessible, and interoperable data, such data is often missing, inaccessible, or fragmented, particularly in emerging markets or complex ecosystem contexts. We used a case study of a Ghana waste recovery ecosystem (WasteGroup) to investigate in depth the specific manifestations of data voids and how key actors work collectively to overcome these challenges by creating data commons, and the implications these challenges pose for businesses seeking to adopt circular principles.

The theoretical foundation of the study is built on the concept of data commons, which refers to collectively managed databases that communities create, maintain, and make available for public access. Rooted in Elinor Ostrom's (1990) work on common-pool resources, data commons emphasize principles of collective governance, shared responsibility, and mutual benefit. This framework is essential for understanding how stakeholders can collaboratively gather and manage data essential for circular economy practices (Hess & Ostrom, 2003). Additionally, the study leverages recent work on datafication, digital innovations, and information ecology to further situate its inquiry. We also referenced concepts from information systems research, such as datafication (turning processes into data), digital mediation (the use of digital tools to transform and structure data), and information ecology (how information circulates in digital and social environments). These lenses help map the process by which data voids are confronted and transformed into actionable, shared resources within the circular economy.

Through a qualitative case study of the WasteGroup initiative in Ghana, the paper identifies a structured process for curating data commons aimed at addressing data voids. The findings are categorized into three key phases:

1. **Collective Imagination**: This phase involves collaborative brainstorming sessions where stakeholders identify critical data needs for effective circular practices. Achieving consensus on data requirements challenges the participants to negotiate and envision potential solutions to existing gaps.
2. **Data Collection**: Once data needs are defined, stakeholders engage in systematic data gathering, which involves manual entry, GPS data collection, and collaboration with diverse entities. This phase highlights the labor-intensive effort required to compile a foundational dataset that can facilitate the envisioned digital solutions.
3. **Digital Mediation**: The final phase involves converting collected data into accessible formats using digital technologies. Stakeholders employ open-source tools and platforms to develop an informational website and resource map, thereby making essential data available to both the public and private sectors.

The paper's key contributions lie in demonstrating how collective action can effectively address data voids and how data commons serve as a vital resource for promoting greater accessibility to essential information. By incorporating grassroots, community-driven approaches into the circular economy discourse, the paper offers valuable insights into how local stakeholders can collaboratively manage and utilize data for sustainable practices.

4.2 Paper 2

Heathcote-Fumador, I.E., Cepa, K., Teigland, R. *(Manuscript Under Peer Review, Information & Organization)* Ecosystem Data Governance: Aligning Data Governance and Ecosystem Orchestration to Address Grand Challenges

The central research question explored in the study is: *How do ecosystem leaders align data governance with their ecosystem orchestration activities to achieve the ecosystem value proposition?* This paper investigates how data governance can be aligned with ecosystem orchestration to support sustainable value creation, drawing on the GhanaWaste study of a circular waste management program in Africa. The central question addressed by the paper is the challenge of aligning data governance with ecosystem orchestration in business ecosystems, particularly those aiming to tackle grand societal challenges. While data are increasingly critical for coordination, monitoring, and evaluation within ecosystems (Susha, 2020; Susha et al., 2019), sharing data across organizational boundaries is fraught with issues related to ownership, quality, privacy, and compliance (Weber et al., 2009). Organizations are often reluctant to share data due to bureaucratic and strategic concerns, even when such sharing could serve the public good (Hillebrand et al., 2023). Existing data governance frameworks, which emphasize formal, contractual mechanisms, are often ill-suited to the organic, trust-based collaborations typical of business ecosystems (Autio, 2022). The paper bridges this gap by exploring how data governance mechanisms can be effectively integrated with ecosystem orchestration activities to enable the creation and maintenance of shared data resources, thereby enhancing the ecosystem's capacity to achieve sustainable value proposition to enable circular economy.

The study is grounded in two primary streams of literature: business ecosystems and data governance. The business ecosystem concept, borrowed from biology, describes networks of firms coordinated by an orchestrator to achieve a joint value proposition (Adner, 2017; Jacobides et al., 2018; Moore, 1993). Orchestration involves aligning and incentivizing complementors, organizations that provide products or services, to contribute to the ecosystem's goals (Adner, 2017; Autio, 2022). Data governance literature, on the other hand, identifies key mechanisms (procedural, structural, relational), decision domains (e.g., data quality, integrity), and scopes (intra- or inter-organizational) for managing data-related challenges (Abraham et al., 2019; Khatri & Brown, 2010; Otto, 2011). The paper integrates these perspectives, arguing that effective data governance does not start with formal structures and procedures but from relational mechanisms that build trust and facilitate voluntary data sharing among actors.

The paper makes several significant contributions to the literature on information systems and business ecosystems:

1. **Integration of Data Governance and Ecosystem Orchestration:** The study demonstrates that inter-organizational data governance is not merely an information systems concern but must be understood within the broader dynamics of business ecosystems. Aligning data governance with ecosystem orchestration enhances the orchestrator's capacity to coordinate complex networks of actors and achieve sustainable value creation.
2. **Elaboration of Governance Mechanisms:** The research advances understanding of the relationships among structural, procedural, and relational data governance mechanisms. It argues that while all three are necessary, relational mechanisms are the primary drivers of structural and procedural governance in ongoing ecosystems.
3. **Introduction of New Roles:** The paper introduces the concepts of "data trustee" and "data stakeholder" to describe the evolving roles of orchestrators and complementors in

ecosystem data governance. These roles facilitate the co-creation of governance procedures and the maintenance of shared data assets.

4.3 Paper 3

Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2024) *Overcoming conflicting linear and circular logics: A process study of how rotating orchestration drives circular ecosystem emergence*

The main research question in this paper is: *How do circular entrepreneurs and organizations overcome clashing mindsets and practices between linear and circular resource production systems?* This question is explored through a case study of an ecosystem focused on recovering ocean plastics for use in large-scale additive manufacturing (3D printing) of furniture in Portugal and Sweden.

The paper addresses a critical challenge in the transition from linear to sustainable circular production and consumption practices. The current linear economic model has led to excessive resource consumption and waste generation, resulting in serious ecological consequences that exceed planetary boundaries. This shift is essential not only for environmental sustainability but also for achieving long-term economic viability. However, the adoption of circular practices is fraught with challenges, particularly for circular entrepreneurs and organizations attempting to integrate circular business models into existing linear systems.

The theoretical foundation of the paper is grounded in the concept of the circular economy and circular strategies, which promote resource efficiency, waste reduction, and a systemic redesign of business practices to align with ecological sustainability. The framework presented in the paper draws on the existing literature on the circular economy ecosystem and sustainable entrepreneurship, positing that organizations must engage in structural transformations to overcome the limitations of linear production models. Specifically, we explore the governance frameworks that can facilitate this structural transformation, "shared leadership," as a viable governance approach that enables distributed orchestration among various stakeholders (Patala et al., 2022).

Through empirical research, the paper identifies four major conflicts that circular organizations face when navigating the transition to circular production systems:

Conflicting Production Valuation: Linear systems prioritize efficiency and cost reduction, often at the expense of sustainability. To overcome this clash, circular entrepreneurs employ various advocacy strategies to disrupt the linear mindset and establish their circular economy vision of a "scaled-out" global network of local microfactories.

Conflicting Materials Valuation: In linear systems, the perception of materials often frames waste as an end-of-life product, whereas circular practices view it as a valuable resource. Circular entrepreneurs purposefully develop new practices for accessing waste: they influence locals to change dumping practices, secure access to recycling resources, and co-create recycling operations.

Conflicting Materials Practices: Existing waste management systems may impede the effective use of recycled materials. Circular Entrepreneurs employ design strategies to develop new practices for accessing waste, influencing locals to change their dumping practices, securing access to recycling resources, and co-creating recycling operations.

Conflicting Production Practices: Traditional manufacturing practices may not align with the flexible, localized production models necessary for circularity. Circular Entrepreneurs employ design strategies to attract and align value chain partners; they network to attract new partners and channel partners' alignment.

These clashes highlight the inherent difficulties in retrofitting circular practices into established linear frameworks, suggesting that a more radical redesign of new circular ecosystems — rather than mere integration — is necessary.

The paper explains how circular entrepreneurs manage to overcome these challenges through shared leadership, which involves collaborative and rotating leadership roles among actors. This approach promotes a cooperative environment where diverse actors can work together to innovate circular production ecosystems.

4.4 Paper 4

Heathcote-Fumador, I.E. *(Working Paper)* Tuning Work as a Representation Mangle: Achieving Circular Production through Additive Manufacturing with Recycled Polymers

The central question addressed by the paper is the lack of empirical understanding of how recycled polymers can be effectively integrated into additive manufacturing processes within a circular economy, at the ecosystem level. I specifically ask these research questions: "*What are the challenges of designing a circular additive manufacturing production process in a complex context subject to physical waste material properties? How do heterogeneous actors mitigate these challenges*?" While prior research has highlighted the potential of Industry 4.0

technologies — such as IoT, data analytics, and digital simulations — to advance circularity (Zeiss et al., 2021; Spaltini et al., 2024), most studies have focused on isolated, single-firm applications and have remained largely conceptual (Aarikka-Stenroos et al., 2021; Kanda et al., 2021; Liu et al., 2022). This narrow focus neglects the complex, inter-organizational coordination required to close, slow, and narrow resource loops at scale. Moreover, the technical challenges of working with recycled polymers — such as material degradation, contamination, and mechanical inconsistencies — are compounded by the fact that digital tools and AM processes are typically optimized for virgin materials (Sharma et al., 2025). The paper thus contributes to this gap by empirically examining how practitioners collaboratively address these challenges through iterative tuning of both digital and physical materials in an ecosystem context.

The theoretical foundation of the paper is based on the concept of circular resource strategies at the ecosystem level. Additionally, the study draws on recent work related to digital representation and employs the tuning concept developed by Pickering (1993) as a theoretical lens to further contextualize its inquiry.

The research employs an interpretive case study (Walsham, 1995) to examine how experts engage in tuning work — a dialectical process of material, process, and design adjustments — to stabilize recycled materials for AM applications. Inspired by Pickering's (1993) concept of tuning, which explains how human and non-human material agencies co-evolve through negotiations, this research identifies three interwoven tuning mechanisms in the AM of recycled polymers.

The findings reveal that three tuning mechanisms work together to overcome the lack of multiple representations, which is referred to in the study as a representation mangle. The three tuning works are intra-domain tuning, cross-domain tuning, and system-external tuning. Intra-domain tuning involves a few interdisciplinary experts and various digital and physical materials. The focus is on closing the loop by improving material reusability and process stability within one or two domain areas. Cross-domain tuning involves multiple interdisciplinary experts as well as multiple digital and physical materials, and captures how tuning spans across domains to stabilize complex representations of print quality, durability, and process constraints. System-external tuning highlights how external knowledge is sourced, translated, and re-integrated to enrich local representations of materials, designs, and simulations.

The study contributes to Circular Economy studies in Information Systems by extending the conversation of representation (Recker et al., 2019, 2021; Zeiss et al., 2021) and digitalized products and everyday life to the realm of circular production (Yoo, 2010; Yoo et al., 2010). It demonstrates that the potential of digital technologies has been overlooked in the context of circular resource strategies for physical materials, focusing solely on the digital aspects of smart products and everyday life. The tuning work presented offers new pathways for representing circular resource strategies in physical products and waste materials, as well as in digital representations, to facilitate digital circular production.

4.5 Synthesis of Papers

Together, the papers illustrate the digitally mediated circular economy as a human-material phenomenon. Each of the ecosystems investigated consists of diverse actors who engage in both human and material activities guided by circular principles of resource stewardship. Their care for physical waste resources and persistence in recovering them through digital means enable them to develop digitally mediated practices.

Paper 1 focuses on how collective data work bridges crucial “data voids” for circular businesses. It presents a process model whereby collective imagination, targeted data collection, and digital mediation build accessible, shared digital resources (data commons) for emergent circular businesses. With the background of the circular economy, digital technologies, and the establishment of a common data resource, **Paper 2** theorizes how data governance mechanisms are integrated with ecosystem orchestration to address grand challenges, that is, transitioning from a linear to a circular economy at the ecosystem level. It shows the relationship between relational, structural, and procedural governance mechanisms, and reveals the emergence of data trustee and stakeholder roles, and how they jointly enable sustainable value creation and capture. **Paper 3** unearths the root cause of challenges circular entrepreneurs face when establishing circular businesses in the current linear economy — specifically, the clash of value systems between linear and circular systems. The linear mindset of take-make-dispose practices clashes with circular practices. Circular businesses must therefore create new practices to overcome these gaps. In this context, it means there are no established practices for circular businesses. Similar to Paper 1, circular businesses must overcome data voids by generating their own data where none currently existed. Arguably, the lack of practices and data in the same domain creates a chicken-and-egg situation. Lack of practices leads to an inability to digitally represent data, which in turn results in data voids and practice voids. Paper 3 conceptualizes the transition from linear to circular logic and provides a detailed empirical case showing how circular entrepreneurs overcome clashes between linear and circular systems. It grounds the story in practical, system-level innovation and introduces key mechanisms (e.g., shared leadership) essential for co-creating new practices. **Paper 4** shifts the focus from broad organizational challenges to technical challenges — specifically, the integration of digital technologies to enable circular production. It explains ecosystem collaboration, highlights the vital role of digital tools, and introduces a theoretical lens — tuning — to analyze the iterative, negotiated adaptation of agency among diverse human and non-human actors. These actors include recycled material, digital technologies, human actors, and circular principles intertwined in digital circular production processes. Overall, the four papers contribute to understanding the digitally mediated circular practices involving human and material tuning practices.

Other publications

1. Öztürk, A. B., Heathcote-Fumador, I. E., McSey, I. A., M'Nkubitu, E., Thomi, D., Wainaina, S., & Taherzadeh, M. J. (2025). Food Waste Management through Machine Learning, IoT, and Blockchain. *In Sustainable Technologies for Food Waste Management (pp. 233-262). CRC Press.*

Conferences and Workshop Presentations

1. Heathcote-Fumador, I.E. (2019): Hosted a Circular Economy Workshop. *Chalmers Sustainability Day, 2019-11-08*

2. Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2022) Keeping the Data Alive: Investigating Data Ecosystem Emergence within a Business Ecosystem. *Act Sustainable Research Conference, Gothenburg Centre for Sustainable Development 2022-06-15 - 2022-06-17*

3. Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2023) The Emergence of a Circular Additive Manufacturing Ecosystem from a Circular Economy Initiative. *Fourteenth International Symposium on Process Organization Studies (PROS) Chania, Greece, 2023-06-18 - 2023-06-21*

4. Heathcote-Fumador, I.E., Cepa, K., Teigland, R. (2025) Ecosystem Data Governance: Aligning Data Governance and Ecosystem Orchestration to Address Grand Challenges in Ghana. *African Academy of Management in affiliation with Ann & Jack Graves Foundation Conference Series, titled "Sustainability as a Solution to Global Business Challenges: A Focus on Africa. Ghana-kumasi 2025-01-12-2025-01-14*

4.6 Interpretive Cross-Case Analysis

In this thesis, I employed an interpretive case study to unravel how the two studies can inform theory on digitally mediated circular practice. Typically, with multiple case studies, and as suggested by Yin (2014), it is good practice to conduct a cross-case analysis to highlight the differences between the cases studied. In this analysis, I followed interpretive analysis (Walsham, 1995) using a theory as a scaffold analytical lens to study a phenomenon. As mentioned above, in this thesis, I employed the mangle of practice lens (Pickering, 1993) as the analytical lens to examine how circular principles are enacted in emergent digitally mediated circular practices within an ecosystem context. Table 7 shows that both Case A and Case B exhibit differences and similarities in their approaches to utilizing digital technologies to facilitate circular strategies informed by circular principles. I collected sample quotations and excerpts from Papers 1, 2, 3, and 4 for episodes of human-material activities. Detailed analysis of Papers 1 to 4 can be seen in Appendix C. The sampling of episodes resulted in human-human and human-material tuning. Others were the reciprocal influence of both tunings, leading to a high-level human-material tuning.

4.6.1 Human-Human Circular Tuning

Collective Imaginations (visioning) tuned to Circular Principles

Case A, GhanaWaste, and Case B, PlasticsOrg, both began with collective envisioning processes. In Case A, participants gathered in both online and offline settings to articulate circular ambitions, share domain expertise, and align their understandings around the future of circular practices. Case B similarly drew on collective imagination, grounded in diverse professional insights and shared values, to inspire and shape their vision. Both cases relied on collective imaginations and shared intention as the foundation for developing circular strategies. While Case A emphasized structured dialogues, Case B allowed for more organic and evolving exchanges, contributing to the emergence of understandings about circular opportunities.

4.6.2 Human-Material Circular Tuning of Digital and Physical Materials

Physical Material Prospecting guided by circular principles.

Prospecting, according to the Oxford Dictionary, means exploring a region or looking for something, and the term has often been used in mining to mean exploring for gold. In a circular economy, instead of extracting virgin raw materials, the exploration can concern discarded materials, spent materials, and products for reuse. In Case A, material prospecting and sourcing were distributed across actors. Although this distributed material sourcing influenced the development of a digital data platform, the material flows and the platform remained loosely coupled. In contrast, Case B actors collectively explored and selected discarded fishing nets as a targeted material stream. They ensured access and availability and integrated this into their production model. Both cases recognized the importance of waste as a valuable resource for circular practices.

Case B displayed stronger material agency through coordinated collective prospecting and systemic integration of waste flows, whereas Case A lacked a unified material engagement strategy, yet individual organizations in the ecosystem exhibited their individual strategies for waste material prospecting.

Digital Material Prospecting Guided by Circular Principles

Both cases explored digital technologies with the potential to enable circular consumption and production. Circular consumption means accessing waste material to be reused based on circular principles, while circular production entails a production process that is guided by circular principles such as resource stewardship. Case A focused on existing technologies and experimented within co-created, predefined technological boundaries. That is, creating a data platform and waste map using free and open-source website tools to meet data needs and make it open and accessible online. Case B, however, actively searched for and tested additive manufacturing technologies that could convert waste into usable products especially suited to local needs. Each case recognized the necessity of technology in operationalizing circular practices.

Case A introduced a digital platform to support decentralized material exchange. Its role was to enhance visibility, connect actors, and facilitate coordination. Yet, because material sourcing was not operationally bound to the platform, its usefulness depended on whether social actors actively engaged with the digital data and acted upon it. In contrast, Case B's approach integrated chosen technologies specifically to suit the transformation of chosen materials.

Physical and Digital (Phygital) Material Tuning to Circular Principles

Both cases illustrate the mangle of practice (Pickering, 1995), where human intentions, material conditions, and technological arrangements become entangled through iterative tuning.

In Case A, data generated from physical activities (e.g., waste collection, sorting) were fed into the digital platform, keeping it current. In turn, the platform provided information about potential material exchange opportunities, partners, and availability. This reciprocal, yet loosely integrated, relationship illustrates a human-material interplay where each component shapes and supports the other. However, the digital platform alone has no intrinsic value unless its information is actively used to facilitate and enhance material exchange. Conversely, physical activities can continue without the digital platform, although likely with reduced coordination and efficiency. This illustrates a conditional interdependence — not a strict coupling — between digital and waste material practices.

In Case B, this tuning was tightly woven; waste streams, technological capabilities, and collaborative goals were dynamically adjusted. This demonstrates a high degree of entanglement between human and material agency. Here, the main goal was to enable digital circular production using Large-Scale Additive Manufacturing (LSAM) with raw materials sourced from a waste stream. A shared vision among the actors led to the decision to use waste material from fishing activities — specifically, discarded PA6 nylon fishing nets.

The interplay between physical and digital considerations necessitated a tuning process in which human actors learned about the behavior of recycled polymers within LSAM processes originally optimized for virgin materials. And the LSAM process is closely connected to recycling waste materials into new products. Without physical materials, LSAM cannot be effective, and without LSAM, new products cannot be printed.

Both cases envisioned, and implemented, different digital technologies to enable their circular goals. However, Case B presented a tightly tuned human-material-technological relationship, while Case A presented a loosely coupled link between human-to-waste material sourcing and human-to-digital technologies, where the value of digital infrastructure was contingent on collective engagement.

4.6.3 Tuning Work between Human-Human and Human-Material tuning

Case B demonstrates a high degree of entanglement between human and material agency. While Case A offers a more distributed and flexible configuration, it reveals the need for sustained human engagement in mediating between data infrastructures and material flows.

In Case A, human actors collectively decided to collect data to monitor and coordinate waste recovery activities and to enable efficient waste material exchange and sourcing. Their circular goals faced significant limitations due to the absence of digital representations of stakeholders, a generally poor local data environment, and a lack of established data collection practices.

To address these data voids, they first compiled a database of all relevant actors. This database supported both operational coordination and public awareness of waste recovery activities, including collection, segregation, upcycling, and exports. They collected business location information, GPS coordinates for drop-off and pick-up points, and details of the specific waste materials handled by each actor. This information allowed actors to identify potential exchange opportunities and helped the public locate waste drop-off points.

The tuning of digital systems to meet physical material requirements also led human actors to assume new data roles alongside their usual activities. Waste recovery actors became data stakeholders, while orchestrators acted as data trustees, entrusted with both sensitive and non-sensitive business information. As a result, physical activities such as coordination and material exchange became more effective due to improved data availability and quality.

In Case B, human-to-human interactions were shaped by material tuning, as actors developed new knowledge about the dependencies between multiple physical and digital materials. The tuning process enhanced the compatibility of recycled materials with production systems and ensured alignment with circular principles, such as designing products that can be reused at the end of their life. This was achieved through a collaborative process where material properties and limitations were revealed in real time, and expert actors expanded their expertise beyond their original domains. For example, process simulation experts acquired new knowledge about recycled polymers, while materials specialists gained insight into LSAM process optimisation. Overall, in both cases, the human actors became influenced by the activities of prospecting and tuning, and as the materials were recovered and transformed, they also gained knowledge spanning across disciplines, and took on new roles depending on the material prospecting and tuning. These repeated activities gave rise to emergent, digitally enabled practices.

Table 7 Cross-Case Analysis of the Human-Material Mangle of Cases A and B

Concepts	Case A activities (GhanaWaste)	Case B activities (PlasticsOrg)	Illustrative Quotation and Excerpts from Papers
Human - Human : Collective Imaginations Tuned to Circular Principles			
Tuning collective imagination to circular principles. They collectively focused their imagination on potential solutions for circular goals through collaboration and idea sharing that influenced their thinking. This also involved a shared understanding of what circular futures could be and how they might be achieved.	Actors gathered in person to collaboratively envision the circular future, brainstorming and sharing ideas and expertise to achieve the circular goal.	During their meetings, both online and in person, they gained more inspiration from all expertise and a circular mindset. This collectively helps them imagine how they can enable a circular future through their collaboration.	"… I think that a huge strength of the project, having all these international partners, it allows for a lot more inspiration. It really gets the imagination going. When you speak to all these people, learn about what they're working on, what their industry in their country is prioritizing, and new technologies that are being developed." (Case B, PlasticsOrg) Collective data requirement co-creation. The foundation of the data commons emerged through collaborative workshops where waste management businesses, coordinators, and IT experts jointly identified critical data needs for circular economy activities. Beginning in 2018, these in-person sessions brought diverse stakeholders together to envision data-driven solutions for Ghana's waste management challenges. Achieving a joint agreement on data requirements proved challenging due to the myriad of ideas about what was possible and what data was necessary. The group engaged in several discussion sessions before arriving at a consensus. As one participant noted, "During that time, we write out what we think, we share it with them. They [businesses] give us their ideas, tell us what is possible, what is not possible. Sometimes, we face challenges where we think it should be possible, and they think it's impossible, but we negotiate along the line and

			eventually come up with something else." (Case A, GhanaWaste) As the ecosystem grew, core sustainable entrepreneurs (i.e., founders of the first circular ventures) began discussing roles and co-developing an understanding of how the different complementors would fit together (Case B, PlasticsOrg).
Material (physical waste and digital technologies) Prospecting			
Waste material prospecting guided by circular principles involves actors intentionally searching for and identifying waste materials that have potential value for circular use, then mobilizing them.	Case A did not prospect waste material collectively; Waste prospecting was done by each actor in the waste management business. The collective considered which waste stream was actively being locally sourced, and how it was recycled by each actor to understand the gravity of problem they are solving.	Actors considered which waste stream could be locally sourced to upcycle to products that met local needs. They decided to focus on discarded fishing nets through a series of search into other discarded waste from fishing activities. They went ahead to create a path to ensure access to the source of waste material for production.	Circular entrepreneurs created the operations for collecting, transporting, sorting, and handling the discarded waste from scratch since there were no previously established practices. Together with local actors, they experimented with numerous methods until they found an optimal process, which began by implementing a pre-sorting system at the port and then transporting the material to the microfactory for further handling by employees as well as members of SocialOrg (Case B, PlasticsOrg).
Digital Technologies prospecting guided by circular principles This involves a purposeful search for and identification of digital technologies with the potential to enable the circular goal.	Actors started exploring existing digital technologies that could be adapted to fill data gaps. Essentially, this meant making information about available waste streams and various waste dealers accessible, and facilitating waste material exchange.	Actors began exploring technologies that have the potential to convert waste streams into products that meet local community needs. They began considering the integration of shredding machines, 3D printers, large-scale additive	"We experimented with different 3D printing options and spoke with experts in the field to understand material compatibility and possibilities." (Case B, PlasticsOrg) The primary activities involved programming and experimenting with various web-based technologies and tools, such as content management systems (CMS) and connecting to different Application Programming Interface (APIs). Upon discussion, the group decided

	Digital technologies were also chosen based on the need to make the information accessible based on circular economy goals, the recycling and reuse. They decided to select a cost-effective, free, and open-source web tool such as WordPress, Drupal and OpenStreet map to create a shared data platform.	manufacturing, and 3D design tools to enhance the process, as well as the use of computers.	to choose free and open-source technologies because the platform is a not-for-profit (Case A, GhanaWaste). For material and location data, IT experts partnered with the open-source community to create a custom digital waste map. This required physical visits to business sites to collect precise GPS coordinates. However, this process revealed significant data inconsistencies as registered business addresses often differed from actual waste collection points, complicating the mapping process. Sometimes, they relied on verbal directions from businesses to locate them, causing challenges "…you call this person and then they're not picking, right? And when they pick up, they will pass you on to someone else. They will say I am not around; I'll give you another number to call. A lot of back and forth" (IT2). Moreover, small waste management businesses were often transitory and were difficult to locate. "Most of the stakeholders weren't permanently positioned; they didn't have offices or anything of the sort, right? Sometimes, too, some of these organizations were run by individuals, right? Or, let me say, their main focal persons were individuals, and either you get them, or you don't get them." (IT1) (Case A, GhanaWaste)
Material (physical waste and digital technologies) Tuning			
Tuning Physical-Material guided by circular principles The tuning and modification of materials — both digital and physical — through practical and technical	In Case A, the digital technology was driven by the need to facilitate waste material exchange, so data on location, owner, and availability were collected	The existing additive manufacturing technologies selected are optimized for virgin materials, not recycled ones. The actors went through a process of	Recycled materials require continuous modification, yet additive manufacturing tools are typically optimized for predictable, standardized virgin plastic material inputs. "The recycled fishing net material is difficult to work with... virgin materials are much safer

means to support circular outcomes. Includes integrating circular principles into existing infrastructure and processes.	to develop the system. This digital technology served as an intermediary to enable the exchange. They experimented with various open-source web tools while encoding data on waste materials to fit into the designs. Making the data available involved engaging with different waste locations and actors to gather waste data and upload this information to the digital platform. The digital technologies in Case A were collectively tuned and are loosely coupled with the physical waste materials. This differs from Case B, where the tuning of digital technologies and physical waste materials was done simultaneously.	tuning the additive manufacturing technologies and their accompanying technologies, like robot code, 3D designs, and simulations, to fit inputs from waste streams. At the same time, they tuned waste into a material that is also optimized for additive manufacturing. In Case B, the waste material and digital technologies tuning were tightly coupled to fit each other's characteristics until an optimal circular production process was achieved. Even though the output was a physical product, the printing process involved a tightly coupled combination of waste material and digital technologies.	because they are designed for specific purposes." (Case B, PlasticsOrg) In response, engineers within the ecosystem engaged in tuning efforts to improve the material so that it aligned with additive manufacturing constraints. "We have to try different methods, make trials, adjust, and try again...it's time-consuming and costly." (Case B, PlasticsOrg) This process is crucial in implementing circular economy strategies, particularly by designing durable products and repairable designs to extend material life cycles. (Case B, PlasticsOrg) A digital data platform was possible as there were existing web technologies and infrastructure that could be adapted through experimentation and reprogramming modules to imagine data platforms. Data were collected and encoded to the web technologies requirements and application requirements (Case A, GhanaWaste). They also chose Drupal and WordPress CMSs to build a website and the custom waste resource map, respectively. They faced challenges in customizing, reprogramming, and adapting to new API changes while experimenting with WordPress and Drupal open-source CMS, as noted by the IT experts: "So even though I'm familiar with Drupal, there was a bit of a learning curve as well as working with Drupal's data structure. Right? Whereas if I was building the application from scratch, it's just a matter of putting together the various, Entity Relationship (ER) diagrams and the architecture and all of those things, right? And then I match up the data values just from a CSV file and I am done. But Drupal has an abstraction

			layer for data management that is querying and inserts so I had to understand how that worked behind the scenes." (Case A, GhanaWaste) Nevertheless, they successfully created an informational website and a custom map detailing each business's locations and the waste materials they recover and recycle.
Overarching Human-Material mangle of practice			
Reciprocal influence of Human-Human and Human-Material Tuning This shows that human-human and the human-material interaction have a reciprocal influence, i.e., that human-human interaction influences human-material and vice versa.	Actors involved in their own business activities were influenced by the material tuning activities and took on data roles to support the data efforts, especially after realizing that there were no set standards to follow for data collection.	In Case B, the ongoing human-human imagination and visioning influenced their experimentation processes of making the materials, both digital and physical, fit the circular production imagination. During the experimentation they shared knowledge about their specific task and challenges, and this process expanded their knowledge beyond their expertise. If they didn't have the expertise to handle a challenge, they spoke to experts outside the ecosystem. Some of the experts outside of the ecosystem joined and consequently the ecosystem expanded.	Some of the actors joined different groups to help fill data gaps and foster innovation. One of the groups was the IT & Data group. "What the IT & Data group primarily does is work on the technology aspect, focusing on how we can integrate various elements, such as the waste map and other related issues, to consolidate all the information we have." (Case A, GhanaWaste) Knowledge sharing among partners about the behavior of materials during their tuning activities extended the actors' knowledge beyond their own domains, as illustrated in the following quotations: "We compile data on how different materials perform in printing and share these insights during project meetings to improve outcomes." (Case B, PasticsOrg) "We experimented with different 3D printing options and spoke with experts in the field to understand material compatibility and possibilities." (Case B, PasticsOrg)

5 Discussion and Conceptual Model Development

The primary objective of this thesis was to examine how digitally mediated circular practices are enacted in emergent ecosystems dealing with a practice void, when no established practice exists.

Through a comparative case study analysis of two cases and appended papers, I develop a conceptual model that explains how circular practices are enacted, guided by human-material tuning to circular principles. The model presents activities that decenter human agency and emphasize a reciprocal, performative agency of non-human actors and humans; it also centers circular principles that influence the multiplicity of agencies.

The model presents a human-material reciprocal agency with six components that enable the emergence of digitally mediated circular economy practices (Figure 3). To overcome the **digitally mediated circular practice void**, the model starts with **circular principles** at the center that inform the **collective imagination** of prospective solutions, **phygital (digital and physical) material prospecting,** and **phygital material tuning**. and finally **human-material dynamics between the human-to-human activities** at the top-center of the model, specifically the tuning of collective imagination, and the **human-material activities area** at the center-bottom of the model. In other words, there is a reciprocal interaction between human imagination tuning work, which involves relational and cognitive human negotiation to tune imagination to circular principles, and human-material tuning work, where there is dialectical human accommodation and material resistance. This dynamic over time results in **the emergence of a digitally mediated circular practice**. And finally, the circular economy practice potentially fills the void of digitally mediated circular practices.

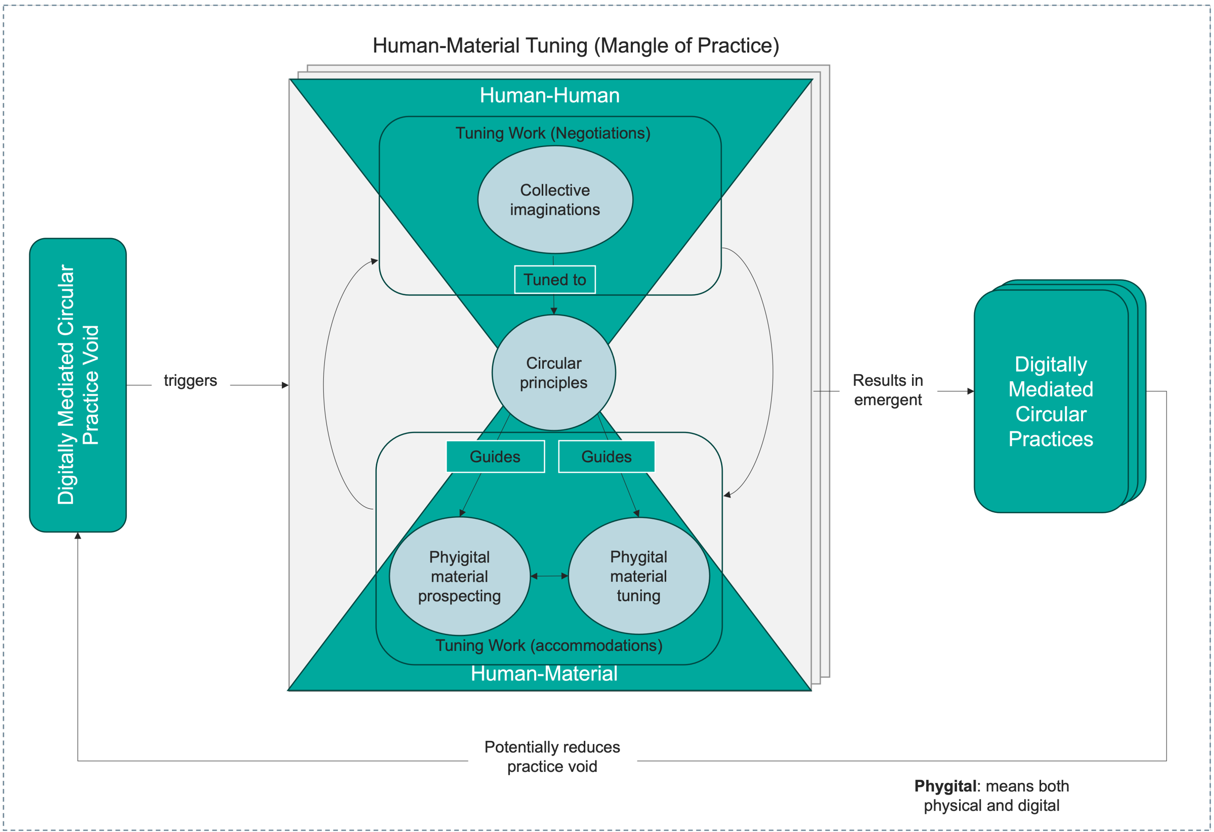

Figure 3: A Conceptual Model of Human-Material Tuning to Enacting Digitally Mediated Circular Practice Emergence

5.1 Digitally Mediated Circular Practice Void

A practice void refers to a situation where no established practices exist. Such voids are particularly prominent in the context of emerging digitally mediated circular economy (CE) initiatives. While the concepts of both circular economy and digital technologies are well-established, their concrete integration and enactment in practice remain nascent. As a result, new practices must be created to bridge this gap.

Despite increasing academic interest, few studies report on the actual implementation of digital technologies in support of circular economy objectives. Practices are not uniform — they vary significantly across industries. For example, circular practices in the built environment (Joensuu et al., 2020) differ from those in manufacturing (Blomsma et al., 2019). Similarly, digitally mediated circular practices diverge depending on the selected technologies, circular strategies, and material characteristics (Kristoffersen et al., 2020).

In the two empirical cases examined, both organizations encountered digitally mediated circular practice voids: Case A aimed to monitor and coordinate waste recovery activities using a data-driven process. However, such a process did not exist, nor could it be easily adapted from existing systems due to the unavailability of necessary data. The organizations also intended to enable digital access to information on waste drop-off and pick-up points, and facilitate material exchange among actors. Yet, these datasets were missing. Consequently, they faced not only a digitally mediated practice void, but also a data void, which hindered progress. Case B encountered a practice void in the domain of digital circular production. Their goal was to use Large Scale Additive Manufacturing (LSAM) to 3D print products from recycled PA6 nylon fishing nets. The use of recycled polymers in LSAM was unprecedented, as the equipment was originally designed for use with virgin materials. The necessary knowledge and routines were non-existent and scarce across different actors and industries. Data on the behaviour of the recycled material was also difficult to access due to the degradation from use and disposal to UV rays. The organization had to integrate fragmented expertise and develop new digitally mediated practices to realize its vision.

Below, I elaborate on how digitally mediated circular practices unfolded.

5.2 Circular Principles

The circular principles component sets the tone for human-material tuning and is at the center of the model, guiding all activities, such as collective imagination, material prospecting, and tuning. These principles come with a degree of ambiguity, as practitioners and researchers alike have contributed various frameworks and so-called R-strategies, such as recycle, reuse, reduce, remanufacture, and refuse (Potting, 2017). These can be used as a starting point to operationalize circular activities. The list of CE principles is ever-expanding, as researchers and practitioners interpret them in various ways. Although the interpretations vary, they all converge on resource stewardship, ISO 59004 (2024), that is, taking care of resources we produce throughout their lifecycle. As I mentioned in 2.1, resource stewardship aligns with my understanding of what a circular principle is, serving as a motive behind actions. This has an influence on sustainable development, a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Hedenus et al., 2018; Keeble, 1988).

Hence, the circular principles component in the model sets the motive behind a path enactment (Feuls et al., 2024) for the possible circular future and informs the actions that form the circular practices filling the practice void.

Case A (GhanaWaste) and Case B (PlasticsOrg) also confirmed this resource stewardship as a circular principle. Their resource stewardship principle motivated them to recover waste from the environment, to prevent the waste from entering the ocean, landfills or incinerators. Their persistence in recovering waste and its value through different means along the value chain led to several activities that enact new practices and innovations.

Human-Material Tuning (Mangle of Practice)

5.3 Human-Human Activities and tuned to circular principles

This is composed of human agency or human intention, achieved through ***collectively tuning imaginations*** to circular principles, aligning visions and ideas with CE principles and imagining potential solutions (Dey & Mason, 2018). The alignment often begins with one actor — usually the orchestrator, who shares initial, immature, circular-driven ideas. Then, the rest of the actors buy in and inspire each other toward a value proposition (Lingens et al., 2021) with the collective imagination process. There is an ongoing negotiation among actors who are committed to circular principles, with some resisting and others accommodating ideas while ensuring they remain aligned with these principles. Both my cases, prospective solutions were collectively imagined through dialogue and presentations of what each one thought was or was not possible for the future.

Human actors internalize CE principles and envision the future, which they then share with others. Together, they collectively imagine and shape the vision. This is similar to a member space (Ollila & Yström, 2025), where there is temporary agreement on a vision and roles. In Case B, the human actors established a shared understanding of the vision for local circular microfactories and ensured they developed a remanufacturing process that aligned with circular economy principles. Individuals begin to take on responsibilities and initiate activities that contribute to the envisioned circular outcomes. They agree on which materials need to be recovered and managed sustainably, as well as which digital infrastructures are suitable for these activities. In Case B, actors agreed that additive manufacturing was more sustainable than injection molding and that its resource input would come from the waste stream. In Case A, the actors decided to utilize a Data Commons platform to make data accessible to all and then brainstormed together to develop a waste map in addition to the Data Commons platform.

5.4 Human-Material Activities

Human-material is the space where digital and physical products and materials to be managed are selected, digital tool requirements are determined, and the resources and processes for developing digitally mediated CE practices are implemented. It is also referred to as the technical system (Leonardi, 2012), where the interaction between material and social actors is intertwined. Two key activities in this system are *Physical and Digital (phygital) Material Prospecting and Tuning*.

The ***phygital material prospecting*** component involves both digital and physical inputs, which are examined, sourced, and mobilized in accordance with CE principles (e.g., resource stewardship). The physical waste materials prospected are *"an opportunity to recapture waste that has already entered the environment"* (Blomsma et al., 2019, p. 9). Both my cases focused on recovering discarded plastic from the environment. Actors then consider which type of waste they want to recover and what value they intend to add to the waste while considering the technologies they can use in accordance with their chosen circular strategy. In Case A, several actors prospected different types of waste materials based on circular strategies, recycling, reuse, or remanufacture. In Case B, the physical inputs were recycled materials sourced by a single actor. The digital components included an additive large-scale robot (both mechanical and digital), 3D digital designs, simulations, and robot code (digital) owned by different actors. In Case B, each actor contributed their data, whether physical or digital, which were standardized into a data object (Alaimo & Kallinikos, 2022), and a digital infrastructure was selected to host this data on a Data Commons platform (Paper 1) (Case A). The waste materials were either to be recovered from the environment or had already been retrieved by individual waste recovery actors. The digital infrastructure created a representation and a waste map to enable search, connection, and circulation of waste materials.

Tuning phygital materials refers to the accommodations that human actors make while using digital technologies to enable material transformation (Case B) or material flows (Case A), as well as the agency and performance of both digital and physical material actors, and their interactions with human intentions. Tuning work occurs within the human-material area, or what Leonardi (2012) refers to as the technical subsystem, the arena where human and material agency intersect. Pickering (1995) described this as a *mangle of practice*, where social actors project their collectively imagined intentions onto materials, and materials, in turn, show agency by responding. Human actors respond with several adjustments referred to as tuning

(Eaton et al., 2015; Pickering, 1993) or *situated accommodations* (Orlikowski, 1996) to arrive at an emergent outcome.

Physical materiality — that is, the agency of waste materials — played an important role during the tuning process. Case A demonstrates that data on the local properties of waste — such as type, size, and location — are essential for enabling material flows for reuse. A key step involved establishing a process by which actors could update information on the material's location, type, size, pick-up/drop-off points, and contact details — referred to as waste-related or actor-related data (Zeiss, 2019). In Case B, the recycled waste materials required further treatment before they could be used in 3D printing production due to the unique demands of 3D printing. Human actors with material expertise found that these materials retained valuable properties after use and that, with the addition of certain fillers and targeted adjustments, the necessary mechanical characteristics for 3D printing could be achieved. This reflection by the human actor shows that waste material can still play a role or perform in the repurposing process — the ideas prompted by the materiality of waste reinforced the actors' agency to recover and repurpose these resources.

Digital materiality, also referred to as the agency of digital materials, likewise played a central role, particularly due to properties of incompleteness and flexibility (Kallinikos et al., 2013; Leonardi, 2011). As the physical waste materials were improved for transformation, digital materials — such as 3D printing/additive manufacturing infrastructure (e.g., robotic code) — enabled dynamic parameter adjustments (e.g., temperature, extruder speed) to align with the materials' properties during the printing process. The 3D software allowed for modifications to the design to enhance structural stability post-printing (Case B). In Case A, a web application software system demonstrated flexibility through its editability and reprogrammability, supporting customization in line with the envisioned digital infrastructure to enable material flow (Yoo, 2010; Yoo et al., 2010). Additionally, online hosting services provided a function for making the platform accessible to all ecosystem actors.

Digital and Physical Materiality Synchronization

Digital materiality aligns well with circular economy practices, which demand flexibility and efficiency to realize circular objectives (Leonardi, 2011). However, waste materials impose constraints that can decelerate the reprogrammability and editability characteristic of digital technologies. For decades, organizational, management, and information systems fields have engaged deeply with digital materiality (Baskerville et al., 2020; Boland et al., 2007; Kallinikos et al., 2013; Yoo, 2010; Yoo et al., 2010). These studies have elaborated on the action possibilities — or digital affordances — and the generativity of digital artefacts (Autio et al., 2018; Majchrzak & Markus, 2012; Malhotra et al., 2021). Digital materials are often conceptualized, in contrast to physical materials, with considerable theoretical effort made to define what digital objects are by anchoring them in reference to physical entities.

Waste materials, by contrast, are physical and exhibit their own affordances and materiality (Leonardi, 2010). While IS scholars are well-versed in the materiality of digital artefacts, it remains necessary to clearly distinguish digital materials from physical ones to avoid conflating their properties. This is particularly important because digital artefacts have long been theorized to exhibit material-like properties — even to the extent of being described as having "matter" despite their intangibility (Leonardi, 2010). This thesis examines the relationship between physical and digital materials in two distinct cases: a tightly coupled relationship in Case B and a loosely coupled relationship in Case A. This necessitates a more precise theorization of each to demonstrate how their distinct materialities are tuned and synchronized toward circular objectives.

Historically, physical materials have been backgrounded in organizational phenomena, considered implicit components of daily life. With the rise of sustainability and CE discourse, however, physical materials are now foregrounded. Once treated as ready-at-hand — used and discarded without reflection — their critical role in sustainable development has become evident (Hedenus et al., 2018; Keeble, 1988). Physical resources have shifted from being implicit to explicitly acknowledged, akin to Heidegger's concept of being "present-at-hand." Recovering these materials requires digital technologies that enable flexible processing, rendering them more visible and actionable in our everyday practices. However, the inherent speed and malleability of digital technologies must be synchronized with the slower, more constrained physical materials that are central for circular economy and for sustainable resource management.

Offline (physical) activities such as recovering, reusing, and recycling cannot be marginalized in CE. At the same time, online (digital) capabilities must be aligned with the constraints and needs of physical material contexts. In Case A, the digital platform's functionality was contingent on the availability of physical data and GPS tagging. Similarly, in Case B, 3D printing activities could only proceed after physical waste had been sourced. This reflects a broader trend where digital circular business models must remain synchronized with offline operations. For example, digitally platform-mediated circular innovation, such as a food packaging reuse initiative, requires coordination with online and offline activities (Recker et al., 2023). Such examples illustrate the design-phase dilemma faced by human actors, who must align physical and digital systems. In this thesis, such synchronization is shown to occur through coordinated efforts during the design phase, wherein physical waste sourcing Case B and waste data collection Case A must precede digital development, often requiring the temporary suspension of digital progress to align with slow-paced physical prerequisites. The physical material prerequisite could also mean other changes to digital materials and vice versa. Yet, if physical materiality informs changes in digital material, the speed can be faster once all requirements are fulfilled than if the digital material informs modifications to the physical material due to physical boundaries. For example, if physical activities must be modified to fit digital requirements, this is arguably much slower than changing a value or code in the digital technologies to represent physical reality. This synchronization of digital and physical components is a crucial step in circular practices, as physical materials cannot be discarded or relegated to the background; they are conspicuous and present in the circular economy. Therefore, synchronization is a complementary step in the tuning process.

5.5 Reciprocal Influence between Human-Human and Human-Material Tuning

The human-material tuning arena embodies the collective imagination of human actors, who are cognitively tuned to circular economy principles; however, it also influences the human-human area by potentially reconfiguring it through co-learning and reflective activities. For example, changes in roles and norms may occur as actors interact and engage in tuning work with the materiality of both digital and physical resources. This was observed in organizations where professional roles were reconfigured to accommodate the materiality of digital infrastructure introduced in the workplace (Barrett et al., 2012). In this thesis, in Case A and Case B, the human-human area evolved to include additional roles and responsibilities. In Case A (Paper 2), the orchestrator became a *data trustee*, and the complementors became *data stakeholders*. In Case B (Paper 3), social actors discussed new roles and co-developed an understanding of how all the components fit together.

This material prospecting and tuning work in the human-material area, together with tuning collective imagination, involves activities influenced by circular principles, leading to an emergent circular economy practice. These tuning works are extensions of the tuning concept in the mangle of practice as presented by (Pickering, 1993, 1995) by adding the voice of circular principle. This also aligns with Pickering's recent book (2025) titled "Acting with the World: Agency in the Anthropocene," which advocates for decentering human agency in the world and for humans to instead collaborate with how the environment works and not get in the way of the natural environment. This contests the narrative of the anthropocentric and technocentric intentions, leading to wicked problems such as climate change, global warming, and a wasteful linear economy. This model complements the acting-with-the-world or nature paradigm to filter out ideas that damage our natural resources and waste man-made resources. Essentially, instead of human-driven concepts, there is a reciprocal tuning process that aligns human agency with the circular principle.

5.6 Digitally mediated circular economy practice

The final component is the emergence of a *stabilized-for-now* CE practice that has the potential to enable a digitally mediated circular economy. Stabilized for now, because more activities, institutional environments (Moreau et al., 2017), or technological changes can influence changes in activities or constrain activities that can alter practices. In the cases studied, the stabilization emerged through iterative adjustments, learning, and coordination among multiple actors. In Case A, the outcome was the creation of a data-enabled waste recovery coordination practice, integrating drop-off and pick-up point information, actor directories, and basic material exchange functionalities. In Case B, the stabilized practice took the form of a digital circular production workflow, enabling large-scale additive manufacturing with recycled PA6 nylon by embedding new material testing, process optimization, and cross-actor knowledge-sharing activities. While these practices currently function effectively, their durability depends on the continued alignment of technologies, actor commitments, and supportive institutional conditions.

Building on human-material tuning and practice studies, and from my model, I define digitally mediated circular practice as *"Embodied, materially mediated arrays of human activity in which human, digital, and physical material agencies are continually adjusted and coordinated, through shared understandings of circular principles, all aimed at sustaining resource value across organizational and ecosystem contexts."*

I would also like to add that the findings and the model can also be applied to non-digital circular practices by omitting the digital aspect. In that case, a circular practice can be defined *as "Embodied, materially mediated arrays of human activity in which human and material* *agencies are continually adjusted and coordinated, through shared understandings of circular principles, all aimed at sustaining resource value across organizational and ecosystem contexts."* A classic example is the story of a Nigerian innovator (https://www.eco-fip.com/) who began exploring plant-based materials to prevent waste and discovered it was possible to make wigs from the plantain stems or trunks. Her intention was to avoid the waste from wigs made of plastic and to reuse plant residues to create sustainable products. She envisioned a process of extracting fibers from the trunks, combing and dyeing them with plant-based substances, and producing wigs that could be reused indefinitely. She then started prospecting material sources and technologies for extraction. Through her team, she was able to identify a manufacturer to support the innovation.

This innovator emphasized that the project was a collective effort. The manufacturer listened to her idea and designed an extractor locally in Nigeria, which became an invention in its own right. Together, they began experimenting and tuning the process of transforming raw plantain waste into a product designed never to become waste again. She explained that they have now reached a point where the process is clear and stable, which is an emergent circular practice that can be replicated and scaled. Through further experimentation, she also discovered additional applications, such as making plant-based bags and sandals. The next step is to acquire more machinery in order to scale up production.

6 Contribution

This study advances scholarly understanding of how digitally mediated circular practices emerge within circular ecosystems by presenting a human-material conceptual model that integrates both human and material tuning and synchronization. This thesis makes three contributions.

6.1 Circular economy

First, this thesis contributes to research on digital sustainability and the circular economy through the development of a conceptual model that presents a human-material tuning, or mangle of practice perspective. The model explains how digitally mediated circular practices emerge from the interplay between collective imaginations and the material prospecting and tuning of material resistances and human accommodations, all shaped by circular principles.

The model introduces a human-phygital material agency to the intersection between CE and IS research, highlighting how digital infrastructure, physical materials, and social processes (e.g., roles, norms) co-evolve through the enactment of circular principles. This addresses a gap in the digitally mediated CE scholarship, which has predominantly prioritized technological innovation (Ciulli et al., 2020; Ranjbari et al., 2024) or the operationalization of CE strategies (Bocken & Ritala, 2021; Urbinati et al., 2017) or sociotechnical dynamics (Blackburn et al., 2023a), neglecting the performativity of physical material in the process. Drawing on insights from post-humanist practice theory (Pickering, 1995), the study underscores the ongoing "tuning work" needed to align digital tools and materialities with circular goals.

This model shows that human-material interaction characterizes circular practices. It incorporates Pickering's (1993) concept of the mangle of practice to analyze the human-material tuning — an arena where practices are negotiated. The mangle emphasizes *tuning work,* i.e., the dynamic interaction between phygital material resistance and human accommodation, through which new practices emerge. It reveals that this part of the activities is not only social or technical or material, but a mangle of human agency, digital infrastructures, and material resource agency mutually constituted in the emergence of circular practices. In the human-material tuning work, physical and digital *prospecting* are interwoven*,* making them available during innovation and production in a circular economy. The human-material activities are influenced by the human (social) actors' embodiment of the collective imagination to enact the circular principles, while the human-material activities potentially reconfigure the collective human imagination, influencing new roles and norms. Together, the human-material tuning results in the emergence of digitally mediated practice.

This thesis also provides a practice-based understanding of how circular principles, digital infrastructures, and material resources mutually constitute the emergence of circular practices, offering explanations for both their enabling and constraining characteristics.

Circular economy (CE) scholars often describe circular practices in terms of waste prevention and regeneration, situated within product life cycles, supply chains, or business models. Previous research has highlighted enabling actions such as recycling, reusing, and reducing — commonly referred to as the 3Rs (Ghisellini et al., 2016). Since then, multiple R-based strategies have emerged, presenting various approaches to waste prevention, elimination, and ecological regeneration.

However, circular practices cannot be reduced to an ever-expanding list of R-strategies such as the 3Rs, 9Rs, or 10Rs (Ghisellini et al., 2016; Potting et al., 2017; Zeiss et al., 2021). Rather, CE is a broader anti-waste movement (Ranjbari et al., 2024) that begins with a change in mindset, materialized through situated action. In line with practice theorists, I argue that recycling, reusing, or reducing are not practices per se unless they are situated within a social context and instantiated through human action (Czarniawska, 2015; Schatzki et al., 2001). This study thus contributes to understanding circular practices as socially enacted and materially mediated, driven by CE principles and involving both digital and physical materials.

Circular principles serve as the motivating force behind actors' alignment, guiding their selection and tuning of materials and digital technologies. These interactions are entangled in the human and material "mangle of practice" (Pickering, 1993) and what others describe as "sociomaterial practice" (Leonardi, 2011, 2012). This entanglement — also referred to as imbrication (Leonardi, 2011) — occurs during the design phase. For example, the CE practice of developing new ways of organizing around Data Commons platforms (Paper 3) redefined social norms by increasing the perceived value of waste materials and their associated data. This human reconfiguration influenced the human activities needed to create such platforms, including data aggregation and data-informed decision-making. Thus, a feedback loop exists between human and human-material tuning activities influenced by circular principles, leading to the emergence of digitally mediated circular practices. This thesis also provides a clear definition for both the circular practice and digitally mediated practice to enhance understanding within the field. I define digitally mediated circular practice as "*Embodied, materially mediated arrays of human activity in which human, digital, and physical material agencies are continually adjusted and coordinated through shared understandings of circular principles, all aimed at maintaining resource value across organizational and ecosystem contexts.*"

6.2 Information Systems

Second, in the Information Systems field, there is an increasing interest in Information Systems for circular economy (Zeiss, 2019; Zeiss et al., 2021). Zeiss et al. (2021) observed the complexity associated with R principles, specifically reuse and recycling, and offered several theories that IS scholarship can employ to advance the circular economy in IS research. These theories included distributed ledgers, open data, data governance, and faithful representations to aid in tracking and tracing the social and material complexity (Zeiss et al., 2021). Other previous studies have explored the role of digital technologies in supporting circular strategies (Kristoffersen et al., 2020; Liu et al., 2022) although they often remain at the conceptual or organizational level, overlooking the complexities of inter-organizational collaboration and the integration of material flows (Zeiss et al., 2021). These previous studies have provided valuable insights and are steps in the right direction; this thesis contributes to this discourse by presenting a deeper understanding of the complexity at the ecosystem level, where recycling and reuse are ongoing. The conceptual model provides empirical insight into the complexity and practices that emerge while enacting circular principles. This study goes beyond technocentric and deterministic approaches, as pioneered by similar researchers' voices (Orlikowski, 1996; Orlikowski & Scott, 2008) for digital organizational research with sociomateriality. It unpacks the physical materiality that complicates the sociomateriality and shows that to move forward with the impact of IS for circularity, physical materiality constraints must be added to the conversation. Studies show that IS studies usually focus on the technical function and what they offer to the circular economy, such as the food-waste sharing platforms (Ciulli et al., 2020; Kurniawan et al., 2022). Digital technologies are considered the enablers of economic value creation or brokers between buyers and sellers. However, other platforms for reusing food packaging show the need to deal with both online growth and offline (physical) constraints (Recker et al., 2023). Specifically, the physical nature and offline reuse activities present challenges to material coordination when users refuse to return reusable packaging and limit the supply to high online requests, and therefore, they need to synchronize the speed of the online platform growth with several mechanisms, such as extra fees, to keep the reusable packaging. This circular practice dynamic emphasizes that platform governance mechanisms, particularly through boundary resources such as APIs, SDKs, and data protocols (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Tiwana et al., 2010) must move beyond the technical governance mechanism and pay more attention to the physical materiality dynamics. These dynamics need further physical offline coordination to accommodate their sustainable management.

This work complements existing studies on CE platforms, which have predominantly examined organizing activities and governance structures (Blackburn et al., 2023b). However, such studies often remain at the social-organizational level, without fully engaging with the dynamic interplay between practical material and technical level. Notable exceptions include Blackburn et al. (2023a), who explore technological affordances in CE contexts from a sociotechnical perspective. Yet even these analyses tend to adopt a deterministic view of technology, prioritizing functionality over relational and emergent dynamics. In contrast, this thesis demonstrates that ecosystem orchestration is not solely a matter of aligning social actors; rather, it involves continuous negotiation across digital infrastructures, material constraints, and human-material interaction. It contributes to the literature by linking micro-level socio-technical practices with macro-level ecosystem transformations (Barrett et al., 2012; Essén & Värlander, 2019). This approach advances the understanding of how CE ecosystems are enacted in practice and how digital and material elements co-shape their development.

6.3 Strategic Management

Thirdly, in the strategic management field, several researchers have contributed to the orchestration of complex social actors in circular economy ecosystems and platforms (Aarikka-Stenroos et al., 2021; Blackburn et al., 2023b; Kaipainen & Aarikka-Stenroos, 2022; Kanda et al., 2021). These contributions build on the foundational work of Adner (2017), Autio (2022) Autio & Thomas (2014), Jacobides et al. (2018), and Thomas et al. (2022),who presented ways to coordinate complex social actors in a non-hierarchical ecosystem through orchestration mechanisms. Additionally, they presented several frameworks, such as the R strategies (Ghisellini et al., 2016) and other circular business model strategies (Bocken & Ritala, 2021; Ritala et al., 2023; Urbinati et al., 2017) that can be operationalized for enabling closing, narrowing, and slowing down material loops. They have remained at the social level, presenting a fragmented understanding of the technical complexity of the human-material interactions involved. The strategies, models, and frameworks provided give a limited understanding of how the circular practices are enacted, specifically in this case, which is digitally mediated. This thesis addresses this gap by providing a human-material understanding of the practice as it is enacted, explaining the interplay between human and human-material activities.

Previous research in strategic management on ecosystem alignment has emphasized the importance of aligning actor interests and shared value propositions to facilitate ecosystem emergence and sustainability (Adner, 2017; Autio, 2022; Autio & Thomas, 2014). This alignment often encounters tensions due to divergent goals, institutional logic, or resource dependencies (Geurts et al., 2022; Huber et al., 2017). Tensions are commonly managed through modular architecture that enables partial coordination while preserving local autonomy (Jacobides et al., 2018). This study shows that tensions can arise from physical and digital material resistance, as well as the demand for ongoing tuning work to resolve these tensions.

This thesis adopts a human-material tuning practice perspective to ecosystem orchestration, supported by empirical insights from multiple papers, to illustrate how distributed tuning works and how human-material practices underpin sustainable circular outcomes. Specifically, it identifies several activities — one human-driven (collective imaginations), two material-driven (material prospecting and tuning works), and reciprocal influence between the human-driven and material-driven activities. These practices are enacted in a distributed and self-organizing manner and are not centered on a single point actor. They collectively enable the emergence of circular practices at the ecosystem level.

Furthermore, it unpacks the mechanisms through which human and material agency co-evolve, including the emergence of new roles and the iterative tuning of digital and physical material resources. The thesis emphasizes the importance of collective imagination (Dey & Mason, 2018) and tuning work among human and material agency. This also aligns with recent calls for attention to the interplay between practice-based individual and organizational agency, and circular ecosystem-centric research (Aarikka-Stenroos et al., 2021; Kanda et al., 2021; Konietzko et al., 2020). I argue that "tuning" is the more suitable term to describe and understand a circular economy ecosystem, rather than "ecosystem orchestration," which prioritizes human intentions to meet their own needs over the well-being of nature. The use of tuning in the context of the circular economy extends the realm of practice to incorporate the voice of resources, thereby mitigating environmental pollution and the depletion of our natural resources through circular principles.

6.4 Practical Implications

This study offers several practical implications for organizations, platform designers, and policymakers engaged in the development and orchestration of digitally mediated circular economy ecosystems.

For organizations and practitioners, the study highlights the importance of recognizing that circular innovation is not solely a technical or managerial challenge but also a human-material tuning process. Managers and ecosystem participants should actively engage in both human activities — such as cultivating shared imaginations — and technical tuning work, including the prospecting and tuning of digital infrastructures in response to material constraints, and vice versa. The successful implementation of circular principles requires ongoing negotiation between human intentions, digital functionalities, and the physical properties of materials, particularly when reuse, recycling, or regenerative processes are involved.

For digital platform designers and developers, the study highlights the importance of designing infrastructures that extend beyond technical scalability and interface design. Digital solutions must accommodate offline material dynamics and facilitate coordination mechanisms that bridge the gap between online interactions and physical resource flows. This includes integrating feedback loops, boundary resources (such as APIs and SDKs), and governance protocols that are responsive to both user behavior and the materialities of circular practices.

For policymakers and ecosystem orchestrators, the findings underscore the need for policy frameworks and funding instruments that support not only the deployment of digital technologies but also the relational work necessary to implement circular practices. This includes investing in capacity building for collaborative ecosystem governance, supporting infrastructure for data and material tracking, and promoting open standards that enable interoperability across platforms. Policies should also be sensitive to the iterative and tuning work that circular practices entail, ensuring flexibility in regulation to accommodate the emergent character of outcomes.

6.5 Limitations and Future Research

This study presents a human-material tuning model that advances understanding of digitally mediated circular practices, yet it is not without limitations. The empirical foundation of the research draws on a limited number of ecosystem cases, which — though rich in contextual detail — are embedded in specific institutional and sectoral environments. As such, the generalizability of the findings across diverse geographies, industries, or policy regimes may be constrained. Additionally, the focus on the emergent phase of ecosystem development means that the study does not fully account for long-term dynamics such as institutional stabilization or transformation over time.

Methodologically, the study adopts an interpretive, practice-based approach that privileges depth over breadth. While this is well-suited for unpacking the entanglement of social and material elements, it necessarily foregrounds micro-level practices and situated negotiations. Consequently, macro-structural influences — such as market mechanisms, geopolitical shifts, or global sustainability agendas — remain analytically backgrounded. Furthermore, while the model articulates the interplay between human actors, digital infrastructures, and material constraints, it does not systematically account for the environmental footprint or energy demands of digital technologies themselves — an increasingly relevant issue within digital sustainability debates.

Future research should pursue comparative and longitudinal studies to examine how digitally mediated circular practices unfold across varying ecosystem contexts and evolve over time. Further inquiry into the role of nonhuman agency — such as the autonomous effects of materials and infrastructures — might enrich the understanding of digital and physical material resistance in practice. Scholars might also explore how platform governance, data protocols, and boundary resources are adapted to accommodate offline material constraints. Interdisciplinary research linking information systems, strategic management, and sustainability science would be particularly valuable in operationalizing the human-material model across diverse sectors and in addressing the normative and ethical questions associated with digital circular transitions.

6.6 Conclusion

This thesis has investigated how digitally mediated circular practices emerge within circular ecosystems by integrating human-material practice-based perspectives, guided by circular economy principles. Drawing on empirical insights from two case studies, the research highlights the dynamic and relational nature of circular economy (CE) implementation, where human agency, digital infrastructures, and material resources co-evolve in shaping circular practices.

By adopting a human-material practice lens, the study contributes to a deeper understanding of how digital and physical materialities interact within complex ecosystems. It shows that circular practices are not linear or predefined processes, but, rather, emergent phenomena formed through iterative tuning, negotiation, and alignment among diverse actors. In particular, this work foregrounds the enabling and constraining roles of both digital artefacts and waste materials, demonstrating how their distinct properties influence practice formation in ecosystems.

The thesis advances the conceptualization of circular principles — not merely as abstract ideals or operational strategies but as performative forces that inform collective imagination, guide actor alignment, and shape technological configurations. This reframing challenges the dominant focus on R-strategies in CE research and offers a richer account of how principles are interpreted locally and materialized in practice.

Furthermore, the research demonstrates that the orchestration of circular ecosystems is not only a matter of managing roles and incentives but also of synchronizing physical and digital processes, accommodating material constraints, and navigating institutional uncertainty. In doing so, it bridges micro-level human-material practices and macro-level ecosystem transformations, contributing to both Information Systems and Strategic Management literature.

7 References

Aarikka-Stenroos, L., Ritala, P., & Thomas, L. D. W. (2021). Circular economy ecosystems: A typology, definitions, and implications. In S. Teerikangas, T. Onkila, K. Koistinen, & M. Mäkelä (Eds.), *Handbook of sustainability and corporate transformation*. Edward Elgar.

Abraham, R., Schneider, J., & vom Brocke, J. (2019). Data governance: A conceptual framework, structured review, and research agenda. *International Journal of Information Management, 49,* 424–438. https://doi.org/10.1016/j.ijinfomgt.2019.07.008

Adelekan, A., & Sharmina, M. (2024). Collaborative digitally-enabled business models for a circular economy: Sustaining, managing and protecting value in the UK plastics sector. *Journal of Cleaner Production, 438,* 140770. https://doi.org/10.1016/j.jclepro.2024.140770

Adner, R. (2017). Ecosystem as structure: An actionable construct for strategy. *Journal of Management, 43*(1), 39–58. https://doi.org/10.1177/0149206316678451

Alaimo, C., & Kallinikos, J. (2022). Organizations decentered: Data objects, technology and knowledge. *Organization Science, 33*(1), 19–37. https://doi.org/10.1287/orsc.2021.1552

Alkki, L., Uusikartano, J., Pohls, E. L., Rusthollkarhu, S., & Aarikka-Stenroos, L. (2024). Unfolding the human–material interaction of material flows in societies: DNA as a conceptual metaphor. *Journal of Industrial Ecology, 28*(2), 339–354. https://doi.org/10.1111/jiec.13473

Autio, E. (2022). Orchestrating ecosystems: A multi-layered framework. *Innovation: Organization and Management, 24*(1), 96–109. https://doi.org/10.1080/14479338.2021.1919120

Autio, E., Nambisan, S., Thomas, L. D. W., & Wright, M. (2018). Digital affordances, spatial affordances, and the genesis of entrepreneurial ecosystems. *Strategic Entrepreneurship Journal, 12*(1), 72–95. https://doi.org/10.1002/sej.1266

Autio, E., & Thomas, L. D. W. (2014). Innovation ecosystems. In M. Dodgson, D. Gann, & N. Phillips (Eds.), *The Oxford handbook of innovation management*. Oxford University Press.

Bag, S., Dhamija, P., Gupta, S., & Sivarajah, U. (2021). Examining the role of procurement 4.0 towards remanufacturing operations and circular economy. *Production Planning & Control, 32*(16), 1368–1383. https://doi.org/10.1080/09537287.2020.1817602

Bag, S., Gupta, S., & Kumar, S. (2021). Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development. *International Journal of Production Economics, 231,* 107844. https://doi.org/10.1016/j.ijpe.2020.107844

Balloni, A. J., de Azevedo, A. M. M., & Silveira, M. A. (2012). Sociotechnical management model for governance of an ecosystem. *International Journal of Managing Information Technology, 4*(3), 1–15. https://doi.org/10.5121/ijmit.2012.4301

Barrett, M., Oborn, E., Orlikowski, W. J., & Yates, J. A. (2012). Reconfiguring boundary relations: Robotic innovations in pharmacy work. *Organization Science, 23*(5), 1448–1466. https://doi.org/10.1287/orsc.1100.0639

Blackburn, O., Ritala, P., & Keränen, J. (2023a). Digital affordances for a circular economy transition: A multiple case study of digital technology-enabled circular business models. In *The Routledge handbook of catalysts for a sustainable circular economy* (pp. 403–421). Routledge. https://doi.org/10.4324/9781003267492-23

Blackburn, O., Ritala, P., & Keränen, J. (2023b). Digital platforms for the circular economy: Exploring meta-organizational orchestration mechanisms. *Organization & Environment, 36*(2), 253–281. https://doi.org/10.1177/10860266221114436

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D. C. A., Hildenbrand, J., Kristinsdottir, A. R., Kristoffersen, E., Shabazi, S., Nielsen, K. D., Jönbrink, A. K., Li, J., Wiik, C., & McAloone, T. C. (2019). Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. *Journal of Cleaner Production, 241,* 118271. https://doi.org/10.1016/j.jclepro.2019.118271

Bocken, N., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N., & Ritala, P. (2021). Six ways to build circular business models. *Journal of Business Strategy, 43*(3), 184–192. https://doi.org/10.1108/JBS-11-2020-0258

Brown, P., Bocken, N., & Balkenende, R. (2019). Why do companies pursue collaborative circular oriented innovation? *Sustainability, 11*(3), 635. https://doi.org/10.3390/su11030635

Burrell, G., & Morgan, G. (1979). *Sociological paradigms and organisational analysis: Elements of the sociology of corporate life*. Ashgate. https://doi.org/10.4324/9781315609751

Cardenas, M., Schivinski, B., & Brennan, L. (2024). Circular practices in the hospitality sector regarding food waste. *Journal of Cleaner Production, 472,* 143452. https://doi.org/10.1016/j.jclepro.2024.143452

Chaudhuri, R., Chatterjee, S., Gupta, S., & Kamble, S. (2023). Green supply chain technology and organization performance: Moderating role of environmental dynamism and product-service innovation capability. *Technovation, 128,* 102857. https://doi.org/10.1016/j.technovation.2023.102857

Chauhan, C., Parida, V., & Dhir, A. (2022). Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises. *Technological Forecasting and Social Change, 177,* 121508. https://doi.org/10.1016/j.techfore.2022.121508

Ciulli, F., Kolk, A., & Boe-Lillegraven, S. (2020). Circularity brokers: Digital platform organizations and waste recovery in food supply chains. *Journal of Business Ethics, 167*(2), 299–331. https://doi.org/10.1007/s10551-019-04160-5

Czarniawska, B. (2015). After practice: A personal reflection. *Nordic Journal of Working Life Studies, 5*(3a), 105–114. https://doi.org/10.19154/njwls.v5i3a.4836

De Pascale, A., Di Vita, G., Giannetto, C., Ioppolo, G., Lanfranchi, M., Limosani, M., & Szopik-Depczyńska, K. (2023). The circular economy implementation at the European Union level: Past, present and future. *Journal of Cleaner Production, 423,* 138658. https://doi.org/10.1016/j.jclepro.2023.138658

Derks, M., Bidmon, C., & Ciulli, F. (2024). Circular e-waste ecosystems in necessity-driven contexts: The impact of formal institutional voids. *Business Strategy and the Environment.* https://doi.org/10.1002/bse.3652

Dey, P., & Mason, C. (2018). Overcoming constraints of collective imagination: An inquiry into activist entrepreneuring, disruptive truth-telling and the creation of 'possible worlds.' *Journal of Business Venturing, 33*(1), 84–99. https://doi.org/10.1016/j.jbusvent.2017.11.002

Eaton, B., Elaluf-Calderwood, S., Sørensen, C., & Yoo, Y. (2015). Distributed tuning of boundary resources: The case of Apple's iOS service system. *MIS Quarterly, 39*(1), 217–243. https://www.misq.org

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review, 14*(4), 532–550. https://doi.org/10.5465/amr.1989.4308385

Ellen MacArthur Foundation. (2013). *Towards a circular economy: Economic and business rationale for an accelerated transition.* Greener Management International. https://doi.org/2012-04-03

Essén, A., & Värlander, S. W. (2019). How technology-afforded practices at the micro-level can generate change at the field level: Theorizing the recursive mechanism actualized in Swedish rheumatology 2000–2014. *MIS Quarterly, 43*(4), 1155–1176. https://doi.org/10.25300/misq/2019/12164

Feuls, M., Hernes, T., & Schultz, M. (2024). Putting distant futures into action: How actors sustain a course of action toward distant-future goals through path enactment. *Academy of Management Journal.* https://doi.org/10.5465/amj.2022.0257

Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. *Journal of Product Innovation Management, 31*(3), 417–433. https://doi.org/10.1111/jpim.12105

Geissdoerfer, M., Santa-Maria, T., Kirchherr, J., & Pelzeter, C. (2023). Drivers and barriers for circular business model innovation. *Business Strategy and the Environment, 32*(6), 3814–3832. https://doi.org/10.1002/bse.3325

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm? *Journal of Cleaner Production, 143,* 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geurts, A., Broekhuizen, T., Dolfsma, W., & Cepa, K. (2022). Tensions in multilateral coopetition: Findings from the disrupted music industry. *Industrial Marketing Management, 105,* 532–547. https://doi.org/10.1016/j.indmarman.2022.06.020

Ghazawneh, A., & Henfridsson, O. (2013). Balancing platform control and external contribution in third-party development: The boundary resources model. *Information Systems Journal, 23*(2), 173–192. https://doi.org/10.1111/j.1365-2575.2012.00406.x

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, 114,* 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gimenez-Fernandez, E. M., Sandulli, F. D., & Bogers, M. (2020). Unpacking liabilities of newness and smallness in innovative start-ups: Investigating the differences in innovation performance between new and older small firms. *Research Policy, 49*(10), 104049. https://doi.org/10.1016/j.respol.2020.104049

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods, 16*(1), 15–31. https://doi.org/10.1177/1094428112452151

Gupta, S., Chen, H., Hazen, B. T., Kaur, S., & Santibañez Gonzalez, E. D. R. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change, 144,* 466–474. https://doi.org/10.1016/j.techfore.2018.06.030

Hart, S. L. (1995). A natural-resource-based view of the firm. *Academy of Management Review, 20*(4), 986–1014. https://doi.org/10.5465/amr.1995.9512280033

Hedenus, F., Persson, M., & Sprei, F. (2018). *Sustainable development: Nuances and perspectives.* Studentlitteratur.

Henry, M., Bauwens, T., Hekkert, M., & Kirchherr, J. (2020). A typology of circular start-ups: An analysis of 128 circular business models. *Journal of Cleaner Production, 245,* 118528. https://doi.org/10.1016/j.jclepro.2019.118528

Henry, M., Hoogenstrijd, T., & Kirchherr, J. (2023). Motivations and identities of "grassroots" circular entrepreneurs: An initial exploration. *Business Strategy and the Environment, 32*(3), 1122–1141. https://doi.org/10.1002/bse.3097

Hess, C., & Ostrom, E. (2003). Ideas, artifacts, and facilities: Information as a common-pool resource. *Law and Contemporary Problems, 66*(2), 111–145. https://doi.org/10.2307/20059162

Hillebrand, K., Hornuf, L., Müller, B., & Vrankar, D. (2023). The social dilemma of big data: Donating personal data to promote social welfare. *Information and Organization, 33*(1), 100452. https://doi.org/10.1016/j.infoandorg.2023.100452

Huber, T. L., Kude, T., & Dibbern, J. (2017). Governance practices in platform ecosystems: Navigating tensions between cocreated value and governance costs. *Information Systems Research, 28*(3), 563–584. https://doi.org/10.1287/isre.2017.0701

Hussain, Z., Mishra, J., & Vanacore, E. (2020). Waste to energy and circular economy: The case of anaerobic digestion. *Journal of Enterprise Information Management, 33*(4), 817–838. https://doi.org/10.1108/jeim-02-2019-0049

Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal, 39*(8), 2255–2276. https://doi.org/10.1002/smj.2904

Joensuu, T., Edelman, H., & Saari, A. (2020). Circular economy practices in the built environment. *Journal of Cleaner Production, 276,* 124215. https://doi.org/10.1016/j.jclepro.2020.124215

Jose, C., Jabbour, C., Lopes De Sousa Jabbour, A. B., Sarkis, J., & Filho, M. G. (2017). Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda. *Technological Forecasting and Social Change, 144,* 546–554. https://doi.org/10.1016/j.techfore.2017.09.010

Kaipainen, J., & Aarikka-Stenroos, L. (2022). How to renew business strategy to achieve sustainability and circularity? A process model of strategic development in incumbent technology companies. *Business Strategy and the Environment, 31*(5), 1947–1963. https://doi.org/10.1002/bse.2992

Kanda, W., Geissdoerfer, M., & Hjelm, O. (2021). From circular business models to circular business ecosystems. *Business Strategy and the Environment, 30*(6), 2814–2829. https://doi.org/10.1002/bse.2796

Kanda, W., Klofsten, M., Bienkowska, D., Henry, M., & Hjelm, O. (2024). Challenges of circular new ventures: An empirical analysis of 70 cases. *Journal of Cleaner Production, 442,* 141103. https://doi.org/10.1016/j.jclepro.2024.141103

Keeble, B. R. (1988). The Brundtland Report: "Our common future." *Medicine and War, 4*(1), 17–25. https://doi.org/10.1080/07488008808408783

Khatri, V., & Brown, C. V. (2010). Designing data governance. *Communications of the ACM, 53*(1), 148–152. https://doi.org/10.1145/1629175.1629210

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular economy: Evidence from the European Union. *Ecological Economics, 150,* 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production, 253,* 119942. https://doi.org/10.1016/j.jclepro.2019.119942

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production, 175,* 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research, 120,* 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044

Kurniawan, T. A., Dzarfan Othman, M. H., Hwang, G. H., & Gikas, P. (2022). Unlocking digital technologies for waste recycling in Industry 4.0 era: A transformation towards a digitalization-based circular economy in Indonesia. *Journal of Cleaner Production, 357,* 131911. https://doi.org/10.1016/j.jclepro.2022.131911

Leonardi, P. M. (2010). Digital materiality? How artifacts without matter, matter. *First Monday, 15*(6). http://firstmonday.org/ojs/index.php/fm/article/view/3036

Leonardi, P. M. (2011). When flexible routines meet flexible technologies: Affordance, constraint, and the imbrication of human and material agencies. *MIS Quarterly, 35*(1), 147–167. https://doi.org/10.2307/23043493

Leonardi, P. M. (2012). Materiality, sociomateriality, and socio-technical systems: What do these terms mean? How are they different? Do we need them? In P. M. Leonardi, B. A. Nardi, & J. Kallinikos (Eds.), *Materiality and organizing: Social interaction in a technological world* (pp. 25–48). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199664054.003.0002

Lingens, B., Miehé, L., & Gassmann, O. (2021). The ecosystem blueprint: How firms shape the design of an ecosystem according to the surrounding conditions. *Long Range Planning, 54*(2), 102043. https://doi.org/10.1016/j.lrp.2020.102043

Liu, Q., Trevisan, A. H., Yang, M., & Mascarenhas, J. (2022). A framework of digital technologies for the circular economy: Digital functions and mechanisms. *Business Strategy and the Environment, 31*(5), 2171–2192. https://doi.org/10.1002/bse.3015

Lopes de Sousa Jabbour, A. B., Latan, H., Chiappetta Jabbour, C. J., & Seles, B. M. R. P. (2023). Does applying a circular business model lead to organizational resilience? Mediating effects of Industry 4.0 and customer integration. *Technological Forecasting and Social Change, 194,* 122672. https://doi.org/10.1016/j.techfore.2023.122672

Majchrzak, A., & Markus, M. L. (2012). Technology affordances and constraints. In *Encyclopedia of management theory*. SAGE. http://ssrn.com/abstract=2192196

Malhotra, A., Majchrzak, A., & Lyytinen, K. (2021). Socio-technical affordances for large-scale collaborations: Introduction to a virtual special issue. *Organization Science, 32*(5), 1371–1390. https://doi.org/10.1287/orsc.2021.1457

Martínez, M. M. M., Buitrago, E. M. E., Yñiguez, R., & Puig-Cabrera, M. (2024). Circular economy and agriculture: Mapping circular practices, drivers, and barriers for traditional table-olive groves. *Sustainable Production and Consumption, 46,* 430–441. https://doi.org/10.1016/j.spc.2024.02.036

McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things.* North Point Press. https://books.google.com/books/about/Cradle_to_Cradle.html?id=KFX5RprPGQ0C

Miles, M., Huberman, M. A., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). SAGE.

Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review, 71*(3), 75–86. https://www.researchgate.net/publication/13172133

Moreau, V., Sahakian, M., van Griethuysen, P., & Vuille, F. (2017). Coming full circle: Why social and institutional dimensions matter for the circular economy. *Journal of Industrial Ecology, 21*(3), 497–506. https://doi.org/10.1111/jiec.12598

NPAP Ghana. (2021). *A roadmap for radical reduction of plastic pollution in Ghana.*
Ollila, S., & Yström, A. (2025). "In-between spaces" for collaborative innovation: Elucidating interrelated relational spaces. *Research in the Sociology of Organizations, 91,* 21–43. https://doi.org/10.1108/S0733-558X20250000091015

Orlikowski, W. J. (1996). Improvising organizational transformation over time: A situated change perspective. *Information Systems Research, 7*(1), 63–92. https://www.jstor.org/stable/23010790

Orlikowski, W. J. (2007). Sociomaterial practices: Exploring technology at work. *Organization Studies, 28*(9), 1435–1448. https://doi.org/10.1177/0170840607081138

Orlikowski, W. J., & Scott, S. V. (2008). Sociomateriality: Challenging the separation of technology, work and organization. *The Academy of Management Annals, 2*(1), 433–474. https://doi.org/10.1080/19416520802211644

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action.* Cambridge University Press.

Otto, B. (2011). Data governance. *Business & Information Systems Engineering, 3*(4), 241–244. https://doi.org/10.1007/s12599-011-0162-8

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

Patala, S., Albareda, L., & Halme, M. (2022). Polycentric governance of privately owned resources in circular economy systems. *Journal of Management Studies, 59*(6), 1563–1596. https://doi.org/10.1111/joms.12769

Pickering, A. (1993). The mangle of practice: Agency and emergence in the sociology of science. *American Journal of Sociology, 99*(3), 559–589. https://doi.org/10.1086/230316

Pickering, A. (1995). *The mangle of practice: Time, agency, and science.* University of Chicago Press. https://books.google.com/books/about/The_Mangle_of_Practice.html?id=UGSaDhK4LZEC

Pickering, A. (2025). *Acting with the world: Agency in the Anthropocene.* Duke University Press. https://doi.org/10.2307/jj.25056653

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain* (Policy report).

Ranjbari, M., Shams Esfandabadi, Z., Siebers, P. O., Pisano, P., & Quatraro, F. (2024). Digitally enabled food sharing platforms towards effective waste management in a circular economy: A system dynamics simulation model. *Technovation, 130,* 102939. https://doi.org/10.1016/j.technovation.2023.102939

Ranta, V., Aarikka-Stenroos, L., Ritala, P., & Mäkinen, S. J. (2018). Exploring institutional drivers and barriers of the circular economy: A cross-regional comparison of China, the US, and Europe. *Resources, Conservation and Recycling, 135,* 70–82.

Ranta, V., Aarikka-Stenroos, L., & Väisänen, J.-M. (2021). Digital technologies catalyzing business model innovation for circular economy — Multiple case study. *Resources, Conservation and Recycling, 164,* 105155.

Recker, J., Bockelmann, T., & Barthel, F. (2023). Growing online-to-offline platform businesses: How Vytal became the world-leading provider of smart reusable food packaging. *Information Systems Journal.*

Recker, J., Indulska, M., Green, P. F., Burton-Jones, A., & Weber, R. (2019). Information systems as representations: A review of the theory and evidence. *Journal of the Association for Information Systems, 20*(6), 735–786. https://doi.org/10.17705/1jais.00550

Recker, J., Lukyanenko, R., Jabbari, M., Samuel, B. M., & Castellanos, A. (2021). From representation to mediation: A new agenda for conceptual modeling research in a digital world. *MIS Quarterly, 45*(1), 269–300. https://doi.org/10.25300/MISQ/2021/16027

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., Von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances.* https://www.science.org

Ritala, P., Bocken, N. M. P., & Konietzko, J. (2023). Three lenses on circular business model innovation. In *Handbook of the Circular Economy: Transitions and Transformation* (pp. 175–190). De Gruyter. https://doi.org/10.1515/9783110723373-014

Rose, J. R., & Bharadwaj, N. (2023). Sustainable innovation: Additive manufacturing and the emergence of a cyclical take-make-transmigrate process at a pioneering industry–university collaboration. *Journal of Product Innovation Management, 40*(4), 433–450. https://doi.org/10.1111/jpim.12671

Schatzki, T. R., Knorr Cetina, K., & von Savigny, E. (2001). *The practice turn in contemporary theory.* Routledge.

Stahel, W. R. (2016). The circular economy. *Nature, 531*(7595), 435–438. https://doi.org/10.1038/531435a

Steffen, W., Noone, K., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., De Wit, C. A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., … Foley, J. (2009). Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society.*

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory.* https://doi.org/10.2307/328955

Susha, I. (2020). Establishing and implementing data collaborations for public good: A critical factor analysis to scale up the practice. *Information Polity, 25*(1), 3–24. https://doi.org/10.3233/IP-180117

Susha, I., Grönlund, Å., & Van Tulder, R. (2019). Data driven social partnerships: Exploring an emergent trend in search of research challenges and questions. *Government Information Quarterly, 36*(1), 112–128. https://doi.org/10.1016/j.giq.2018.11.002

Thomas, L. D. W., Autio, E., & Gann, D. M. (2022). Processes of ecosystem emergence. *Technovation, 115,* 102441.

Tiwana, A., Konsynski, B., & Bush, A. A. (2010). Platform evolution: Coevolution of platform architecture, governance, and environmental dynamics. *Information Systems Research, 21*(4), 675–687. https://doi.org/10.1287/isre.1100.0323

Turner, C., Okorie, O., Emmanouilidis, C., & Oyekan, J. (2022). Circular production and maintenance of automotive parts: An Internet of Things (IoT) data framework and practice review. *Computers in Industry, 136,* 103593. https://doi.org/10.1016/j.compind.2021.103593

Upadhayay, N. B., Rocchetta, S., Gupta, S., Kamble, S., & Stekelorum, R. (2024). Blazing the trail: The role of digital and green servitization on technological innovation. *Technovation, 130.* https://doi.org/10.1016/j.technovation.2023.102922

Urbinati, A., Chiaroni, D., & Chiesa, V. (2017). Towards a new taxonomy of circular economy business models. *Journal of Cleaner Production, 168,* 487–498. https://doi.org/10.1016/j.jclepro.2017.09.047

Van de Ven, A. H. (2007). *Engaged scholarship: A guide for organizational and social research.*

Vermunt, D. A., Negro, S. O., Verweij, P. A., Kuppens, D. V., & Hekkert, M. P. (2019). Exploring barriers to implementing different circular business models. *Journal of Cleaner Production, 222,* 891–902. https://doi.org/10.1016/j.jclepro.2019.03.052

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management, 22*(2), 195–219. https://doi.org/10.1108/01443570210414329

Walsham, G. (1995). Interpretive case studies in IS research: Nature and method. *European Journal of Information Systems, 4*(2), 74–81. https://doi.org/10.1057/ejis.1995.9

Weber, K., Otto, B., & Österle, H. (2009). One size does not fit all: A contingency approach to data governance. *Journal of Data and Information Quality, 1*(1), 1–27. https://doi.org/10.1145/1515693.1515696

Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). SAGE.

Yoo, Y. (2010). Computing in everyday life: A call for research on experiential computing. *MIS Quarterly, 34*(2), 213–231. https://doi.org/10.2307/20721426

Yoo, Y., Boland, R. J., Lyytinen, K., & Majchrzak, A. (2012). Organizing for innovation in the digitized world. *Organization Science, 23*(5), 1398–1408. https://doi.org/10.1287/orsc.1120.0771

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research, 21*(4), 724–735. https://doi.org/10.1287/isre.1100.0322

Zeiss, R. (2019). Information flows in circular economy practices. In *Proceedings of the 27th European Conference on Information Systems (ECIS)*. https://aisel.aisnet.org/ecis2019_rp/38

Zeiss, R., Ixmeier, A., Recker, J., & Kranz, J. (2021). Mobilising information systems scholarship for a circular economy: Review, synthesis, and directions for future research. *Information Systems Journal, 31*(1), 148–183. https://doi.org/10.1111/isj.12305

Zhu, Q., Geng, Y., & Lai, K. H. (2010). Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. *Journal of Environmental Management, 91*(6), 1324–1331. https://doi.org/10.1016/j.jenvman.2010.02.013

8 Appendix

8.1 Appendix A

An invitation for an interview for research purposes

Dear [participant name],

I hope you are well.
I am contacting you because you have made a great contribution to the UNDP Waste Recovery Initiative in Ghana.

I am a PhD student at Chalmers University of Technology in Sweden. I was born and raised in Ghana, and I am currently working on circular economy initiatives, innovations, and technologies.
And I am interested in learning more about UNDP's Waste Recovery Initiative in Ghana.

I am speaking with stakeholders involved in the initiative to learn more, and Kingsley and Catherine at UNDP have recommended you as one of the key individuals I should speak with. Are you open to this? If so, please respond to this email. We can set up a Zoom or a face-to-face meeting if you are available.

Please choose a day and time when I can call you. Use the link below

https://calendly.com/ida-heathcote-fumador/an-invitation-to-a-research-interview?month=2022-02

Figure A1 Email Template for Interviewees

Table A1 Interview protocol for Case A

Concepts	Data Governance Questions	Who
Interviewee's experience	How long have you worked with your organizations? How long have you been involved with UNDP waste recovery platform.	All Actors
Interaction (Purpose)	What is the role of your organization in the collaboration? What are the main goals of the collaboration? What is your own role in the collaboration? What is your main responsibility?	

	Has this role changed during the collaboration?	
Data use case	Why are data important for this collaboration? Do you think data will be more or less important as this collaboration develops and moves towards its goals? Why?	
Data position	Which data are important for this collaboration? Which data have you and/or your organization contributed? Which data do other organizations contribute? Who decides which data are contributed?	
Data use case	Why are data important for this collaboration? Do you think data will be more or less important as this collaboration develops and moves towards its goals? Why?	
Data Ownership	Who owns the data that are contributed to the collaboration? Who can access the data? How are data ownership and access rights decided? How are data-related disputes resolved? Do people care about the data collected and claim ownership? How?	Orchestrators
Regulatory Environment	What data / security policies, standards, guidelines,	Orchestrators

	regulations do you need to follow? How does the collaboration identify and decide which ones to follow? Who decides? How do the regulations etc influence the use of data? How do you keep up to date with the regulations, etc? Whose responsibility is it to keep up to date? How do you ensure that you actually comply with/follow the relevant regulations?	
Data Processing	Describe your process of data collection. How do you decide which data are necessary? Where do they come from? E.g., in-house, sourced externally? How has your data collection process/strategy changed over time?	All
Data Management	How are the data stored? Where are they stored? How are the data secured? How are the data prepared? Who does this? Are the data combined with other data? Why and how? How are the data maintained? Who?	Orchestrators
Data Access rights	How are you personally working with the data? How are the data accessed? What can you do with the data?	
Data Hurdles Conformance	What have been the data-related challenges in your collaboration?	

	Have you had any data security issues/challenges? Have there been any misunderstandings related to the data and its use in the collaboration? What has worked well that you didn't expect? What are the challenges moving forward?	
Contribution Measurements	How well is the project achieving its intended goals?	
Decision rights on data - Trust, transparency, Polycentric/ Monocentric Transparency with the use of data and sharing decision rights Revenue sharing- reward for data contributors	Do people share information with others? To what extent are people help each other? Can you give an example a time when one actor helped another actor? Can you tell me a time when there was a conflict? How was it resolved?	
Structure	Who formulates all the rules? Who has the most say?	
Mechanisms	Can you explain how decisions are made?	
Data Privacy and Security	How do you protect the rights of the data owner? How do you protect your data? Have you had problems with people accessing the data you shared publicly? Has any actor complained about the data privacy?	Orchestrators

	Is there anything else you would like to add?	

8.2 Appendix B

Email Draft Inviting Interviewees

! Action Required | An invitation for an interview for research purposes

Dear [name],

I am reaching out to you because you have made a great contribution to Ocean-LSAM and/or Peniche Ocean watch.

I am a PhD student at Chalmers University of Technology in Sweden. I am currently working on circular economy initiatives, innovations, and technologies.

And I am interested in learning more about Ocean-LSAM. I am talking to stakeholders involved in the project to learn more, and Robin Teigland recommended you as one of the key people I should talk to.
Are you open to this? If so, please click this link to choose a time or respond with your selected time. I will send you a zoom invitation later.

Med vänliga hälsningar/ Best regards

Ida Eyi Heathcote-Fumador

Doctoral Student | Doktorand

Technology Management and Economics | Teknikens ekonomi och organisation

Entrepreneurship & Strategy

ida.heathcote.fumador@chalmers.se +46 31 772 62 48

Figure B1 Email Template for Case B

Table B2 Interview Guide Case B

Theme	**Interview Questions**
General introduction	Can you give a brief background and history about your venture / your role? What was your key motivation to start your venture / your role? What were your assumptions of the market/industry before starting your venture? What surprised you?

	How did the market/ industry receive your product? What is your impression of the impact of the project?
Opportunity Recognition how they discovered an opportunity	What led you to become aware of this opportunity? How did you feel when you first learned about this opportunity, and how has that feeling evolved over time? Can you walk me through the process of how you discovered this opportunity? OCEAN -LSAM Was there a specific event or conversation that sparked your interest in this opportunity? Did you actively seek out this opportunity or did it come to you? Were you already familiar with the industry or field that this opportunity is in, or did it introduce you to something new? How did you evaluate whether this opportunity was a good fit for you? What motivated you to pursue this opportunity? What other opportunities did you consider before deciding to pursue this one? Did you have any mentors or advisors who helped you discover or evaluate this opportunity?
Are Actors driven by profit or circular innovation:	How do you measure success in your role? Can you describe a project or initiative you were involved in that you are particularly proud of? What role do you think innovation plays in your field? Can you give an example of a time when you took a risk to try something new or different? How do you balance the need to generate profit with the desire to pursue innovative ideas? How do you prioritize projects or initiatives when resources are limited? Do you have any examples of how you have successfully balanced short-term profits with long-term goals? Can you describe a time when you had to make a difficult decision between pursuing a profitable opportunity and investing in innovation? How do you stay up to date with new trends and developments in your industry, and how does that influence your approach to work?

Value-creating challenges: making positive long-term contribution to society	What is the value that you provide to society? What challenges did this entail for you and your team? How did you solve those challenges? What tools/methods did you use when working with this challenge? What is the role of Digital technologies in your value creation? What challenges did digital technologies present?
Funding challenges: bringing money into the sustainable venture	What are your ways to sustain your project financially? What challenges did this entail for you and your team? How did you solve those challenges? What tools/methods did you use when working with this challenge?
Systemic challenges: enablers and barriers in the external environment	Can you tell us about the environment where you operate? How do the characteristics of the systems (economic, social, political, technological, etc.) impact your operations? What challenges did this entail for you and your team? How did you solve those challenges? What tools/methods did you use when working with this challenge?
Human collaboration challenges: team and coordination issues	How have you organized internally to push your project forward? What challenges did this entail for you and your team? How did you solve those challenges? What tools/methods did you use when working with this challenge?
Final thoughts on challenges.	What has been the most challenging part of your experience? What has been the most helpful tool/method for facilitating and/or reflecting on your work? What are your future plans in the short-term and long-term?

Are they driven by profit or social impact:	What motivates you in your work? How do you measure success in your role? Can you describe a project or initiative you were involved in that had a positive social impact? How important is it to you to have a positive social impact through your work? Can you give an example of a time when you had to make a difficult decision between pursuing profits and pursuing a social impact? How do you balance the need to generate profit with the desire to create positive social change? What role do you think businesses have in creating positive social change? Can you give an example of how you have successfully aligned profit goals with social impact goals in the past? How do you stay up to date with social issues and trends, and how does that influence your approach to work? Can you describe a time when you had to convince stakeholders or team members of the importance of pursuing a social impact goal, and how you approached that situation?
Collective or Individualistic agency	How do you see your role in this project/initiative? How do you define success in this project/initiative? Can you describe a time when you worked effectively as part of a team? Can you describe a time when you took initiative to improve a project or process?
The role of Digital Technologies in this context.	What digital technologies are you currently using in your work? How have these digital technologies changed the way you work? What benefits do you see in using digital technologies in your work? Are there any challenges or limitations to using digital technologies in your work? How has the use of digital technologies impacted communication and collaboration among group members? Are there any additional digital technologies that could benefit your work?

8.3 Appendix C

8.3.1 Data analysis Case A GhanaWaste (Papers 1 and 2)

My data analysis followed the grounded theory (Gioia et al., 2013) inductive approach by allowing the data to speak to me instead of categorizing data based on pre-informed theories. All data, interviews, recorded meetings and archival materials were uploaded to a coding software called Atalas.ti. My two co-authors and I started with open coding (Strauss & Corbin, 1998): I coded two interviews, which were then checked and discussed by the other two authors. The other two authors then coded two interviews each before comparing, discussing, and clarifying to keep the concepts close to the informants' accounts. All authors then coded collaboratively on the web version of Atlas.ti, while checking, reading, and commenting on each other's coding.

This open coding resulted in several first-order codes, which we subsequently merged, split, and changed according to our evolving understanding of the case (Gioia et al., 2013). This phase of first-order code refinement went hand-in-hand with axial coding (Strauss & Corbin, 1998), and we arrived at a reduced set of first-order codes, which we grouped into a group of second-order categories. In iterative steps, and with recourse to the literature on data innovation, digital mediation, business ecosystems, data governance, and stakeholder theory, we arrived at eight aggregate dimensions and our final data structure. There were too many to fit in one paper because they were full of too many concepts. So, I decided to focus on the data curation to fill data gaps for paper 1 and data governance for paper 2. The development of paper 1 demanded additional data, hence the second round of data described above.

8.3.2 Data analysis Case B PlasticsOrg (Papers 3 and 4)

I drew on process ontology (Langley, 1999) to understand how circular entrepreneurs form new circular ecosystems to overcome conflicting production and material values (Tsoukas & Chia, 2002). Process ontology, a philosophical perspective, views the world as constantly evolving and undergoing transformation. According to Tsoukas and Chia (2002), organization scientists should prioritize the study of microscopic changes to gain insights into the underlying mechanisms that drive an organization's transition between various states or forms. By focusing on these microscopic steps, researchers can uncover the dynamic processes that shape organizational behavior and structure. By adopting this process ontology, together with my coauthors, we analyzed how the project unfolded over time, paying attention to specific events, temporality, and the specific practices that caused changes over time. The research and analysis were used to develop papers 3 and 4. Paper 1 showcased the process study of how circular entrepreneurs overcome challenges to establish a circular business in a system dominated by a linear product system. Paper 4 focuses on micro-practices during the innovation process of creating recycled polymer for large-scale additive manufacturing applications, employing an interpretive case study through the lens of mangle of practice theory.

8.4 Appendix D

Regional strategies for advancing local digital circular economy practices.

There were also differences in the digital technical approaches in the regions where the two cases were situated. The contextual differences provide insights into the level of infrastructure and technical capabilities of both Europe and Africa in terms of available possibilities and the lack of established practices for implementing digitally enabled circular practices. They also highlight government involvement and policy development in Africa and Europe in support of circular projects. In the African context, the initiative is organized by the Ghana branch of the United Nations Development Programme (UNDP) and funded through their internal resources, private organizations, and embassies. Meanwhile, in the European context of Case B, it was funded by the government of Sweden, demonstrating the political and governmental will to support circular and sustainable projects.

Additionally, the choice and use of technologies were tailored to local needs, particularly the need to address the gap in digital circular practices. In Case A, the African context, they face a lack of data on various distributed systems, which hinders scaling and efficient circular flow of materials to potential recyclers and upcyclers. Therefore, the digital technologies aimed to fill the data gap to lower the transactional costs associated with physical sorting methods for partnerships. The technology sought to facilitate waste material exchange as a solution for businesses' circular consumption of waste raw materials. In Case B, the European context, the absence of practices in circular production was targeted. The approach involved leveraging existing research institutes, highly skilled industry experts, and large additive manufacturing capabilities. These are expensive infrastructures that startups may not afford, but collaboration with industry partners willing to learn and co-create circular production using waste materials as raw materials was pursued. The Swedish government's support and funding opportunities for research and innovation also boosted the development of circular production. Access to advanced infrastructure, research institutes focused on production, and government funding played key roles in Case B.