THE CIRCULAR SHIFT

A Design Science Approach to Developing a Circular Capability Maturity Tool for Firms

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PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus prof.dr. S.K. Lenaerts, voor een commissie aangewezen door het College voor Promoties, in het openbaar te verdedigen op dinsdag 26 mei 2026 om 16:00 uur

door

Adrianus Antonius Cornelis Maria Wierikx

geboren te Oud en Nieuw Gastel

Dit proefschrift is goedgekeurd door de promotoren en de samenstelling van de promotiecommissie is als volgt:

Voorzitter:	prof. dr. ir. G.J.J.A.N. van Houtum
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Het onderzoek of ontwerp dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

To my father.

In the silence of your absence,

your voice still echoes,

steady, strong,

and always building.

This is for you.

Contents

List of Figures

List of Tables

Contents

List of Abbreviations

ADKAR	Awareness, Desire, Knowledge, Ability and Reinforcement
AVE	Average Variance Extracted
BASIC	Beginner's All-purpose Symbolic Instruction Code
BOM	Brabantse Ontwikkelings Maatschappij (Brabant Development Agency)
BVC	Beroepenveld Commissie (Professional Advisery Board)
CA	Cronbach's Alpha
CBMM	Circular Business Model Maturation in Logistics
CDP	Carbon Disclosure Project
CE	Circular Economy
CMB	Common Method Bias
CGRi	Circularity Gap Report initiative
CR	Composite Reliability
CMT	Circular Maturity Tool
CVPAT	Cross-Validated Predictive Ability Test
DS	Design Science
DSS	Decision Support System
DSVF	Design Science Validity Framework
EM	Expectation-Maximization
EPA	Environmental Protection Agency (United States)
EPR	Extended Producer Responsibility
ERP	Enterprise Resource Planning
ESG	Environmental, Social, and Governance
EU	European Union
GHG	Greenhouse Gas
HTMT	Heterotrait-Monotrait ratio
HU	Hogeschool Utrecht
HVA	Hogeschool van Amsterdam
ICER	Integrale Circulaire Economie Rapportage
IoT	Internet of Things
IT	Information Technology
ITEM	Innovation, Technology, Entrepreneurship and Marketing
IPB	Institute for People and Business
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LM	Linear Model
LSEG	London Stock Exchange Group
MAR	Missing At Random
MCAR	Missing Completely at Random

MIS	Missie-gedreven Innovatie Systeem (Mission-driven Innovation System)
MFA	Material Flow Analysis
MM	Maturity Model
MNAR	Missing Not At Random
NLP	Neuro-Linguistic Programming
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OSF	Open Science Framework
OWW	Onder Water Week (Under Water Week)
PhD	Doctor of Philosophy
PLS-SEM	Partial Least Squares Structural Equation Modeling
PPE	Plant, Property and Equipment
PRIME	Practice-based Research Impact Model for Evaluation
RBV	Resource-Based View
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
RRfW	Resource Recovery from Waste
SCOR	Supply Chain Operations Reference
SER	Sociaal Economische Raad
SLR	Systematic Literature Review
SME	Small and Medium Enterprises
TBL	Triple Bottom Line
TNO	Toegepast Natuurwetenschappelijk Onderzoek
TU/e	Eindhoven University of Technology
UCCT	Utrecht Centre for Circular Transition
VBDO	Dutch Association of Investors for Sustainable Development
VCR	Video Cassette Recorder
VIF	Variance Inflation Factor
VLM	Vereniging Logistiek Management (Association for Logistics Management)
VLW	Vervoerslogistieke Werkdagen
VRIN	Valuable, Rare, Inimitable, and Non-substitutable
WBCSD	World Business Council for Sustainable Development
WUR	Wageningen University and Research

Acknowledgements

Prologue

Acknowledgements

Over the past 35 years, I have had the privilege of meeting people from all around the world. Countless conversations have inspired and energized me, enriched by the ideas and opinions generously shared. During my time at Delft University of Technology, I made a promise to myself to develop the discipline of collecting, keeping, and digitizing the business cards of the people I met. You never know how a contact might one day play a role in your life, an insight, I discovered later, that echoes the work of Jaworski (2011). Later, LinkedIn made it even easier to maintain these connections, helping me build a vibrant professional network.

This PhD journey builds on the inspiration, energy, and ideas of the many people I have encountered. Each and every one of them has contributed to shaping who I am and to creating the dissertation I present today. It is simply not possible to thank them all personally. There are, however, several people whose support has been especially meaningful in helping me complete this PhD. Their help, and the essence of who they are, have enabled this journey.

First of all, I would like to thank ***my parents Kees and Nellie***. It is thanks to you that I have been able to fulfill my dreams. You taught me to be curious, to explore, and to follow what feels meaningful. You have alway given me the space to follow my own path. Unfortunately my father is no longer with us. So many questions I wish I could still ask him, so many conversations I would love to have with him. Nevertheless, somehow or other, I know he's there. Somewhere.

I would also like to thank ***my brother Jeroen and my sister Tonnie***. Although we don't talk about work that often, your presence, encouragement, and interest in what I am doing have always meant a lot to me. Thank you for being my cornerstones.

Another big thank you goes to the ***Route Circulair Team and Arjan van den Born from ROM Utrecht.*** Arjan, when my company was a case study for your PhD research around 2008, who could have thought that some 15 years later, you would support mine by connecting me with Jaimy from Route Circulair. As I said before, this was meant to be. ***Jaimy, Guido, Sjoerd, Matthijs (2x), Annemiek, Rowie, Brigitte, Jeanette, Krista, Margot, Dorien, Jorian, and all the other (former) Route Circulair impactmakers,*** I cannot thank you enough for working side by side to make this project happen. We had and still have a mutual mission: 10,000 firms making the transition to circular by 2030. We believe(d) in this mission and began collaborating.

Today, the energy is still there, the mission is progressing (over 3,000 completions, firms that started their transition as of April 2026), and the list of things we want to do together is growing. Through our cooperation, we have mutually accomplished a lot. Not just building the tool together, not just collecting data together, not just working on this PhD project. Through our cooperation, we have made a significant impact at local, national, and international levels. We succeeded and are increasingly successful in creating awareness globally about what it takes to adopt circular principles. A big thank you. Without our cooperation, this PhD would not be complete at this point, and I doubt whether it could have happened at all. However, please note that our cooperation does not end here with this dissertation. Far from it. This is not a full stop, but a comma in our relationship. The model has been developed and validated. There are new opportunities on the horizon. And we started yesterday.

Although we worked hard with the Route Circulair team, collecting all the data, conducting all the interviews, it would not have been possible without the positive involvement of a number of pioneers. At the risk of forgetting someone, I mention: ***Greg Bruininkx*** (former Province of Utrecht policy advisor) allowing us access to Utrecht based firms to collect data, ***Waldo Maaskant*** at Noord Brabant council, working with us and the ImpactX team in the high tech value chains, ***Bart van Straten*** at van Straten Medical, offering hospitality, giving guest lectures, etc. and of course the 100 interviewees and over 3,000 participants who completed surveys. Please realize how important your contribution was to making this research a success. Also a special thanks to the ***ImpactX team (Esther, Lodewijk, and Dheebak)*** with whom we worked in the Circular Value Center and on the High Tech Project. A special thank you also to the expert panel members for validating the alpha version and participating in the Delphi Rounds: ***Leon van Ast, Carolien van Beek, Maartje Bodde, Anne van Bruggen, Greg Bruininkx, Rolf Gelpke, Antoine Heideveld, Ton van Kollenburg, Inge Oskam, Dijs Punt, Pascal Ravesteijn, Pascal Sluiter, Helen Toxopeus and Dennis Vegter***.

I also express my sincere gratitude to the individuals and organizations who expressed their initial support for this PhD research through endorsement letters. Their early encouragement and belief in the value of this research provided the confidence and foundation I needed to embark on this project. Without that initial trust and backing, this dissertation might never have taken shape. These supporting parties are listed in Table 57 of Appendix M. Next, I sincerely thank a number of people at ***HU Utrecht University of Applied Sciences***. First of all, ***Ronald Antonissen*** and ***Eva Reuling***, thank you for believing in me and allowing me to join the organization's payroll. That step was essential for starting this PhD journey. Eva (in your current role on the Executive Board), together with ***Gerard van Assem and Wilma Scholte op Reimer***, thank you for listening to my continual pleas to give circularity its rightful place on our agenda, and for

embracing the idea of joining Circular Utrecht. I am truly grateful that we are now part of this initiative. Looking ahead, I sincerely hope to enjoy the continued support and collaboration with the Executive Board in further developing the Utrecht Center for Circular Transition (UCCT). It would be a strong sign, both internally and externally, of our shared commitment to accelerating the transition to a circular future.

To the management team members of the ***Institute for People and Business (IPB)***: thank you for your patience and for repeatedly granting me the time to focus on my PhD work. Please know that I deeply appreciate this flexibility. That appreciation also extends to the IPB support team. I am grateful that, time after time, you accounted for my PhD days and OnderWaterWeken (OWW) when scheduling.

Within IPB, I also want to thank my ***(former) colleagues in the Logistics Management team***. I have valued our conversations about my research and I truly appreciate your understanding when I had to cancel meetings due to research commitments. I also apologize for occasionally slipping into 'research geek' mode during team discussions or student assessments. ***André, Annemarie, Arjan, Bart, Dionne, Frans-Luuk, Jeroen, John, Omar, and Wim***: thank you for your patience.

A very special thanks goes to ***Nathalie Deurhof***. As the captain of the Logistics Management team, you helped me tremendously in learning to say no and in prioritizing what truly mattered. You also did the heavy lifting behind the scenes to ensure that I had the time needed to work on my dissertation. That support made a big difference in maintaining the right pace.

From a support perspective, I also would like to explicitly thank the ***Research Support Team, Appie and Margreet***. Your expertise in which tools to use, how to configure them, and how to handle data effectively made the process significantly smoother. It may seem simple, but a seamless research process is by no means guaranteed. I am also grateful for the range of software tools made available, supporting everything from transcription and data analysis to writing and reference management (these are acknowledged in Appendix O).

Finally, my heartfelt thanks go to my colleagues in the Process Innovation & Innovation Systems Research Group, led by ***Pascal Ravesteijn***. ***Anand, Carolijn, Cora, Erik, Frans, Gido, Guido, Iris, Leontine, Marja, Nerko, Pascal, Paul, Philippine, and Willemijn***, I have lost count of how many times we discussed something related to our PhD research. Although I was not always present, I deeply appreciated our biweekly meetings as a moment to share thoughts, challenges, and progress. These interactions helped me ask better questions and view texts more critically.

Pascal, I think it takes both courage and talent to lead a group of independently-minded researchers in a way that makes everyone feel at home, valued, and engaged, while also ensuring the group remains productive. During the past five years, we have built a working relationship that has been both effective and fulfilling, and it has given me the opportunity to learn more than I ever expected.

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Besides my colleagues at HU, I would also like to extend special thanks to several people at ***Eindhoven University of Technology***. I would like to express my deep appreciation to my promoters, ***Néomie and Alex***. Thank you for your guidance, critical insights, and continuous support. Although this was my fourth attempt at a PhD, I soon realized how much I still had to learn about academic research and publishing. With your help, I found the direction and discipline I needed to grow into this role. I hope our collaboration continues; there are still papers to write, and plenty of data to explore.

I am indebted to ***Sjoerd Romme*** for his valuable feedback on my work and for the inspiration and insights he provided during his PhD course on Design Science, which influenced my thinking and methodological approach. Finally, a heartfelt thank you to ***Astrid*** and ***Bianca*** in the ITEM back-office team. Your support helped me navigate my way through ITEM, IE&IS, and the broader Eindhoven University of Technology. And thank you especially for managing to schedule meetings in calendars that seemed fully booked.

In addition to the special individuals I've worked closely with in recent years, I'm also deeply grateful for the communities and networks I've been part of, whether through collaboration, regular meetings, or shared interests. The discussions, reflections, and interactions within these groups, often sparked by sharing bits and pieces of my research and its challenges, have contributed more than they might realize. They've led to new ideas, creative solutions, renewed motivation, and sometimes simply offered the space to pause, take a breath, or regain perspective. The ***Phoenix Intervision Group, with Erika, Hilde, Monique, Robin, and Vincent***, has been a constant source of reflection and encouragement. The ***Logistics Management Beroepenveld Commission (BVC), with Mieke, Tiemen, Jos, Sander, Peter, Mark, Bart, and Pieter-Jan,*** has contributed valuable professional perspectives.

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I feel truly privileged to have had such an experienced and supportive supervisory team guiding me throughout this study. ***Néomie, Alex, and Pascal*:** Your combined expertise, commitment, and critical yet constructive guidance made all the difference. Thank you for helping me grow as a researcher and for keeping the project on track, even when I occasionally veered off course.

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On a personal note, I want to say sorry to the many friends whom I have barely spoken to in the past four years. I have learned that doing a PhD means that the research never really leaves your mind: it is always there, in the background. While swimming, running, hiking, and cycling helped to clear my head, keeping in touch with others quietly slipped into the background for a while.

Peter and Christiaan, I really appreciate that we still managed to catch up from time to time. Thank you both for taking the time to talk, it meant more than you might realize.

A special place in this dissertation belongs to those closest to me, ***my wife Marjolein, and our children. Thomas, Hugo, Flint, Yana, and Lois***: I know that the details of what I was doing did not dominate your thoughts, and that is perfectly fine. What mattered most was that you gave me the space and support I needed to see this through. Whether it was fewer or shorter phone calls, honest feedback on your own theses, or simply understanding that we had a little less time together, you supported me and I am deeply grateful for that. It truly felt like the right time to take on this challenge. I still had the energy, you were all grown up and capable of taking care of yourselves and so far we have no grandchildren (yet!). That window of opportunity made this possible.

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More than just a listener, you often offered thoughtful suggestions and ideas for improvement. Even when my stubbornness did not allow me to see their value right away, many of those insights ultimately shaped my research. Your presence, your belief in me, and your contributions, large and small, have meant the world.
To me, you are my forever person. In many ways, it feels as though we have written this dissertation together.
Thank you.

‘Life unfolds not only

through plans and logic,

but also through resonance,

intuition, and meaningful

connection’.

~ Jaworski, 2011

Prologue

Over the course of my life, I have come to embrace a quiet but enduring conviction: that every event carries meaning, even if it takes years to understand what that meaning is. What first appears as coincidence is often revealed, with time and reflection, as something far more intentional.

This insight echoes the work of Joe Jaworski, who I met in 2009 and who described synchronicity as the phenomenon whereby once one commits deeply to a path, unseen forces begin to align, supporting that goal (Jaworski, 2011). His writing gave language to something I had long felt but never quite articulated: that life unfolds not only through plans and logic, but also through resonance, intuition, and meaningful connection (Jaworski, 2011).

From this belief, two philosophical sensibilities have grown side by side in me. On the one hand, a constructivist mindset, trusting that meaning is not discovered but co-created through context, perception, and interaction. On the other hand, a neo-positivist impulse: the desire for clarity, structure, and evidence.

I was born in 1966 in Stampersgat, a village in the West Brabant region, into a family of entrepreneurs. My father, grandfather, and great-grandfather all ran construction companies, so my path seemed predestined. Stampersgat is also home to what once was and still is the largest beet sugar factory in the world.

Sugar beets are a remarkable crop. During the beet campaign, all beets must be transported from the fields to the factory within just a few months. In that period, everything that can drive or sail is called into action. This is where my passion for logistics was born.

I grew up in nearby Dinteloord, on an industrial estate surrounded by warehouses and transport companies. West Brabant, located between Rotterdam and Antwerp, evolved into one of the Netherlands' major logistics hotspots. I spent time observing the locks, sluices, ports, rivers, canals, barges, and trucks. Unmistakably, my love for logistics took root.

As a child, I organized my mother's pantry, telling her what to buy to avoid stock-outs and what to use first to prevent waste. I cleaned my father's warehouse, salvaging what others might have thrown away. In hindsight, this was when I first became averse to waste and interested in circularity.

Only later did I learn that 1966, the year I was born, was also when Kenneth Boulding wrote The Economics of the Coming Spaceship Earth, a foundational essay in circular thinking (Boulding, 1966). Referring again to Jaworski's ideas: it was meant to be. Conversations with Waldo Maaskant later made me realize that sugar beet is in fact a powerful example of circularity. Once cultivated primarily for sugar, nearly all parts of the beet are now repurposed: the pulp becomes animal feed, the molasses is used in fermentation and bio-based products, and even residual lime finds its way back into agriculture. Today, sugar is just one of many valuable outputs in an increasingly circular system.

From the money I earned working in my father's company, I initially wanted to buy a VCR to record movies. My father, observing my many hobbies, asked a simple but powerful question: *"When will you actually have time to watch those movies?"* Instead, he encouraged me to consider something more revolutionary: a personal computer. And so I did. A Commodore 64 entered our home. I played games, wrote poems, and, most importantly, began learning to program in BASIC and use Lotus 1-2-3 (the predecessor of Excel). Later, I replaced the Commodore with an Atari ST and started automating warehouse operations in my father's company. My passion for IT was born, and it has never left me.

Given this background, it was no surprise that I chose to study Civil Engineering at Delft University of Technology. I pursued a self-designed "free doctorate" program, combining courses from two universities and five faculties. At the time, there were no dedicated master programs in supply chain management or logistics, so I forged my own path, focusing on logistics and IT.

After graduating, I wanted to deepen my understanding of logistics and chose to join TNO. Under the supervision of Professor Kees Ruijgrok, I appreciated the freedom to conduct research and manage projects. Among others, I worked with Marja Exalto-Sijbrands, who was pursuing her PhD, and I began my first exploration into the possibility of doing the same. However, I also felt a strong pull towards gaining real-world experience before committing to such an academic path.

When I left TNO in 1995, I told Kees Ruijgrok that I genuinely enjoyed research, and that it wouldn't surprise me if I returned to it 25 years later.

I then joined Baan Company, a leading ERP vendor. There, I had the privilege of working closely with Jan and Paul Baan, traveling the world and operating at the intersection of logistics and IT, advocating, training in, and promoting the Orgware concept.

I also had the opportunity to collaborate with Professor Hans Wortmann, affiliated with Eindhoven University of Technology. With him, I began my second exploration into doctoral research.

However, the combination of a rapidly growing family and an exploding business, at a time when Baan briefly became a global leader in ERP, proved incompatible with the focus required for a PhD. That initiative came to a halt.

Alex Alblas was one of my promoters. Sadly, Professor Wortmann had passed away, yet in a meaningful way, life has come full circle: Hans Wortmann previously supervised Alex Alblas as his promoter.

One of the most important lessons I learned during my time at Baan was: successful implementation is not about software, nor about hardware, it's about orgware: the human side of change. It hinges on whether people can genuinely answer the question "What's in it for me?" and wholeheartedly say yes to the change that lies ahead. As an engineer, specialized in IT and logistics, understanding what drives people was not originally part of my skill set. Recognizing this gap, I decided to expand my expertise and undertook training in the human dynamics of change. Jan Baan introduced me to Tjeb Maris. The two of us had many discussions about Servant Leadership and how to link it to large-scale projects. I read his book and the book by Robert Greenleaf (Greenleaf, 1977; Maris, 2000).

After my time at Baan, I co-founded Mondea in 2000 together with Arjen Joosse. Unsurprisingly, our work focused on complex strategic challenges at the intersection of logistics and IT. At the time, I was often told that my approach was "too academic." Ironically, today I more often hear the opposite: "it could be a bit more academic."

During this period, I also served as the CEO of the Dutch Association for Logistics Management (*VLM - Vereniging Logistiek Management*), working closely with its chair, Professor Tom van Woensel and later Professor Jack van der Veen. It was with Jack that I began my third attempt at PhD research. Yet again, the sheer multitude of responsibilities, both personal and professional, halted that effort.

In 2010, we celebrated Mondea's ten-year anniversary. I vividly remember Willem Zwiers, one of the other shareholders, saying to me: *"Arjen, enjoy this party, and please realize that such high points can only exist because there are also low points."* That remark has stayed with me ever since, resurfacing in moments of both clarity and difficulty.

In the following years, the “old” Mondea days did not really return. Partly due to personal challenges, I also found myself increasingly caught up in running the day-to-day business rather than getting deeply involved in client projects.

After my divorce, I found new love and married Marjolein in 2015. With less focus on growth but a deeper sense of purpose, Mondea continued to engage in meaningful projects at the intersection of IT, logistics, and change management. During this time, I also broadened my expertise by pursuing studies in Neuro-Linguistic Programming (NLP), Transactional Analysis, organizational and family constellations, and the ADKAR Change Management methodology.

In 2019, I attended an open day at HU University of Applied Sciences with my son Hugo. Unsurprisingly, he too expressed the desire to become an entrepreneur. Our conversations that day had two outcomes: he enrolled in the Small Business and Retail Management program, and I was invited to give a series of guest lectures.

Those guest lectures sparked a new connection. I was approached by the program manager of the full-time Bachelor’s in Logistics Management, who asked whether I would be interested in teaching and helping to shape the new curriculum. And that is what happened.

To my surprise, or perhaps not, I soon reconnected with my former TNO colleague, Marja Exalto-Sijbrands. She introduced me to lector Pascal Ravesteijn, who, interestingly, also had ties to Baan. We were both surprised that our paths had not crossed earlier. Marja recalled my earlier PhD attempt at TNO, and Pascal mentioned a new opportunity: a four-year PhD trajectory, funded by HU University of Applied Sciences, allowing candidates to spend three days per week on research. The only requirement? Employment at the university.

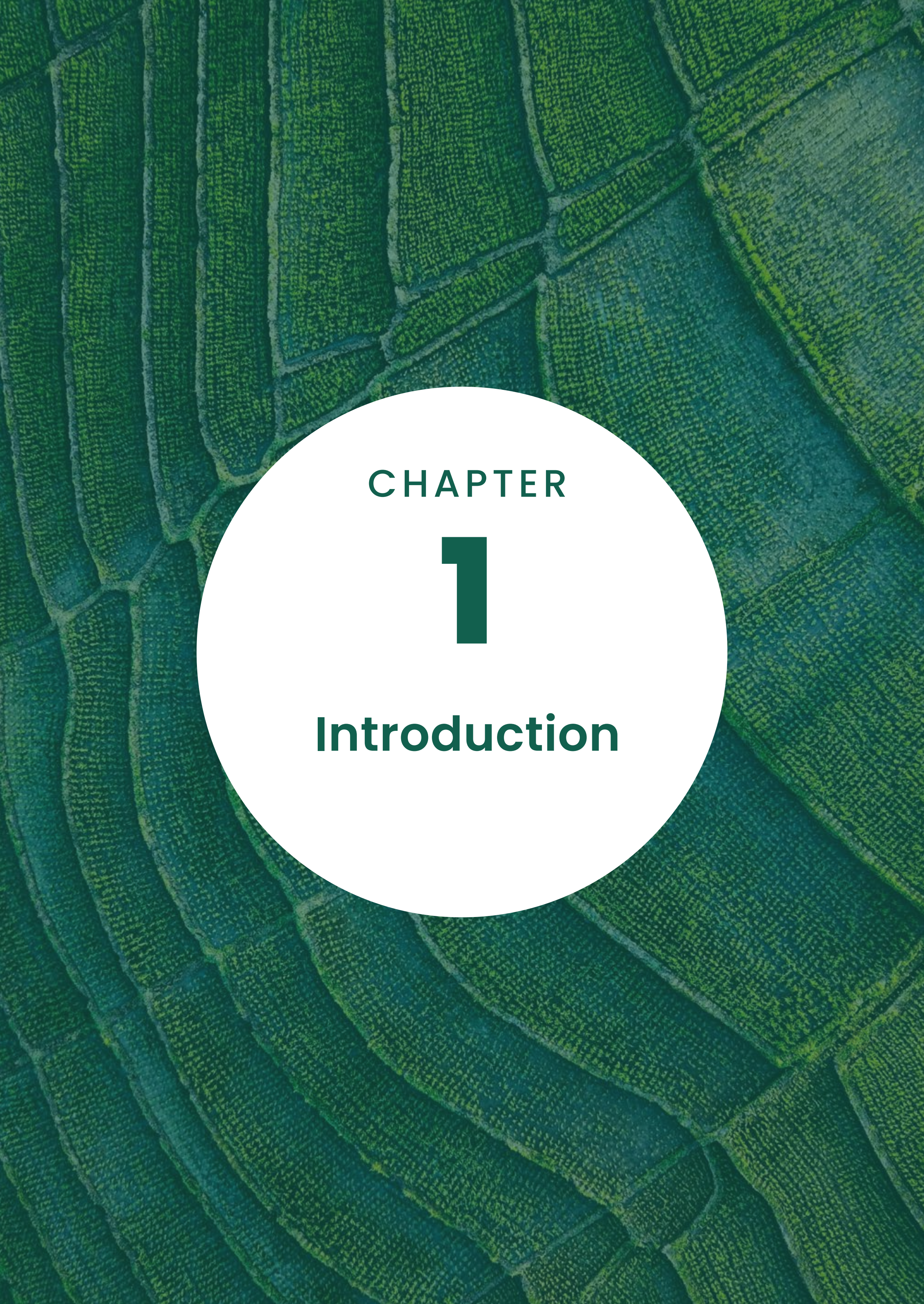
When I started my PhD at the HU University of Applied Sciences in 2020, I made a significant career shift. I left twenty years of entrepreneurship, building companies, experiencing success, and enduring failure. It took me four sleepless nights to come to terms with this paradigm shift: from the perceived freedom of entrepreneurship to the structured reality of a salaried position. I returned to a world I had only briefly encountered during my years at TNO (1992–1995): the world of research and education.

In June 2020, exactly 25 years after leaving TNO, I signed a contract with HU University of Applied Sciences. In a remarkable echo of the past, just as my father once exchanged entrepreneurship for a career in education after two decades, I found myself making the very same transition. That, I believe, is no coincidence.

After nearly a year of shaping and refining the research proposal, the HU University of Applied Sciences PhD voucher was officially granted in June 2021. My doctoral journey formally began that September. It was my fourth attempt, and this time I got the green light and all the essential ingredients were finally in place.

The research lies at the intersection of IT, logistics, and change management, rooted in my passion for logistics and a deep-seated aversion to waste. Or, in the words of HU University of Applied Sciences's slogan: this is where everything comes together. Where the circle finally closes. Sadly, Professor Kees Ruijgrok, under whose guidance my academic journey began, passed away recently and will not witness the completion of this path. In a paper co-authored with Professor Lóri Tavasszy (former study mate and colleague at TNO), Dr. Ron van Duin, and Dr. Pascal Ravesteijn (my co-promotor), I pay tribute to Kees's legacy by linking his foundational ideas with my research. The paper was presented in May 2025 at the Vervoerslogistieke Werkdagen (VLW), an academic conference Kees helped to establish. It is available, in Dutch, via the online appendices (see Appendix L #02).

This dissertation is where it all converges: technology, logistics, people, and purpose. The work is not only the product of academic rigor, but also the outcome of a lifelong search for coherence in complex systems. In that sense, it is more than research, it is a reflection of everything that has moved me, professionally and personally, to ask better questions.



CHAPTER 1

Introduction

1 Introduction

1.1 The World is Not Enough: Growth Ambitions versus Planetary Boundaries

A confluence of global mega-trends is pushing the boundaries of the traditional economy, which has long relied on resource-intensive, throughput-driven production and consumption models (Geissdoerfer et al., 2017). Climate change, resource scarcity, geopolitical instability, and tightening environmental regulations are collectively challenging the long-standing "take-make-waste model" of economic growth (Geissdoerfer et al., 2017; Murray et al., 2017). The result is mounting pressure on firms to reduce their environmental footprint while securing access to critical resources in a volatile global market (Blomsma & Brennan, 2017). At the same time, societal expectations are shifting: customers, investors, and regulators increasingly demand transparency, responsibility, and measurable impact in terms of environmental and social outcomes (Kirchherr et al., 2017). In this landscape, Circular Economy (CE) principles, such as resource retention, closed-loop systems, and regenerative design, have gained traction as a strategic response, promising both ecological resilience and long-term competitiveness (Stahel, 2016).

Several governments have articulated CE strategies as policy frameworks that support the transition to CE. The EU's CE Action Plan positions circularity as a key pillar of the European Green Deal, targeting product design, waste prevention, and material reuse in high-impact sectors such as electronics, construction, and batteries (European Commission, 2020a). In 2023, the EU refined its monitoring framework to better track progress and ensure coherence with critical raw material policies (European Commission, 2023).

The Netherlands stands out with one of the most ambitious goals: a complete CE by 2050, and a 50% reduction in the use of primary abiotic raw materials by 2030. These goals are operationalized through the Dutch National CE Program 2023–2030, which introduces sector-specific roadmaps and regulatory instruments to drive material circularity across value chains (Government of the Netherlands, 2023). Other EU member states have also advanced policy frameworks. France adopted the Anti-Waste and CE Law (2020), which includes mandatory repair indices, bans on the destruction of unsold goods, and stronger producer responsibility schemes (Ministère de la Transition écologique France, 2020). Finland, meanwhile, aims to become a waste-free society by 2050, embedding circularity in education, innovation, and public procurement (Ministry of the Environment, Finland, 2021).

These national strategies indicate a growing consensus: managing the demand for raw materials through CE design, reuse, and recycling is not only an environmental imperative, but also essential for economic resilience and geopolitical stability.

However, despite growing awareness, policy ambition, and industrial initiatives, this momentum has not yet resulted in meaningful global progress (Ellen MacArthur Foundation, 2013; Verleye et al., 2024). On the contrary, the world is becoming less circular: the share of reused materials in the global economy has steadily declined over the past decade. According to the Circularity Gap Reporting initiative (CGRi), global circularity dropped from 9.1% in 2018 (Circle Economy, 2018) to a mere 6.9% in 2025 (Circle Economy, 2025) (see Table 1). This stark trajectory signals a deeper structural truth: more than 93% of extracted materials are still not being cycled back into the economy.

Table 1: CGRi's Global Circularity Rates (2018–2025)

Year	Circularity Rate	Key Observation
2018	9.1%	CGRi's inaugural global benchmark (Circle Economy, 2018).
2020	8.6%	Decline amid increased global discourse (Circle Economy, 2020a).
2023	7.2%	Worsening trend; material demand intensifies (Circle Economy, 2023).
2025	6.9%	Record low; urgent need for systemic shift (Circle Economy, 2025).

The deteriorating trajectory challenges the basic premise of a circular transition. While circularity is often cited as a key component of climate and resource strategies, the reality reveals a widening implementation gap. Addressing this gap requires understanding how firms translate CE ambitions into concrete practices at the operational and strategic level (Delmas et al., 2019; Triguero et al., 2023).

While the CGRi data, presented in Table 1, exposes a systemic gap at the global level, transitions do not materialize solely through high-level metrics; they often begin at firm level (Triguero et al., 2023; Werning & Spinler, 2019). Firms play a pivotal role in the operationalization of CE strategies because they control critical levers of material use, design, production, and distribution. Through innovation, such as eco-design, material substitution, or digital tracking, firms can reduce resource intensity at the source (Blomsma & Brennan, 2017; Kirchherr et al., 2017; Stahel, 2016). By reconfiguring supply chains to enable take-back systems, industrial symbiosis, or local sourcing, it is possible to establish closed-loop systems that facilitate the recirculation of materials and minimize waste. Transitions in business models, such as shifting from ownership of products to service-based models (e.g., leasing or product-as-a-service), exemplify

Circular Business Models (CBMs) that enable firms to align profitability with resource efficiency (Aarikka-Stenroos et al., 2022). Firms are not merely passive recipients of policy, but active agents in sustainability transitions, that is, in broader socio-technical shifts in which CE developments are embedded, capable of reshaping markets and institutional structures (Delmas et al., 2019; Lüdeke-Freund et al., 2024). Sustainable entrepreneurship, seen as an entrepreneurial activity that pursues environmental and social objectives alongside economic ones, as well as the emergence of CBMs, have been identified as key levers for accelerating material efficiency and decoupling growth from resource extraction (Bocken et al., 2014; Hörisch, 2015). Thus, while macro indicators provide essential diagnostics, the engine driving the transition is often firm-level action (Javaid et al., 2019). By embedding CE principles into strategic decision-making, firms can simultaneously address environmental challenges and unlock economic opportunities through CBMs (Stahel, 2016; World Economic Forum, 2014).

1.2 The Gordian Knot: Fragmented Contributions and the Need for Integration

In the past decade, scholars have sought to operationalize CE at the firm level through two primary research approaches: developing CE performance indicators and designing CE Maturity Models (MMs) (Kreutzer et al., 2023) (see Figure 1). Though these research approaches have contributed meaningful insights and advanced the field in important ways, as shown in more detail below, reviewing these approaches also reveals two overarching research gaps, both conceptual and methodological in nature, which together shape the research problem addressed in this dissertation.

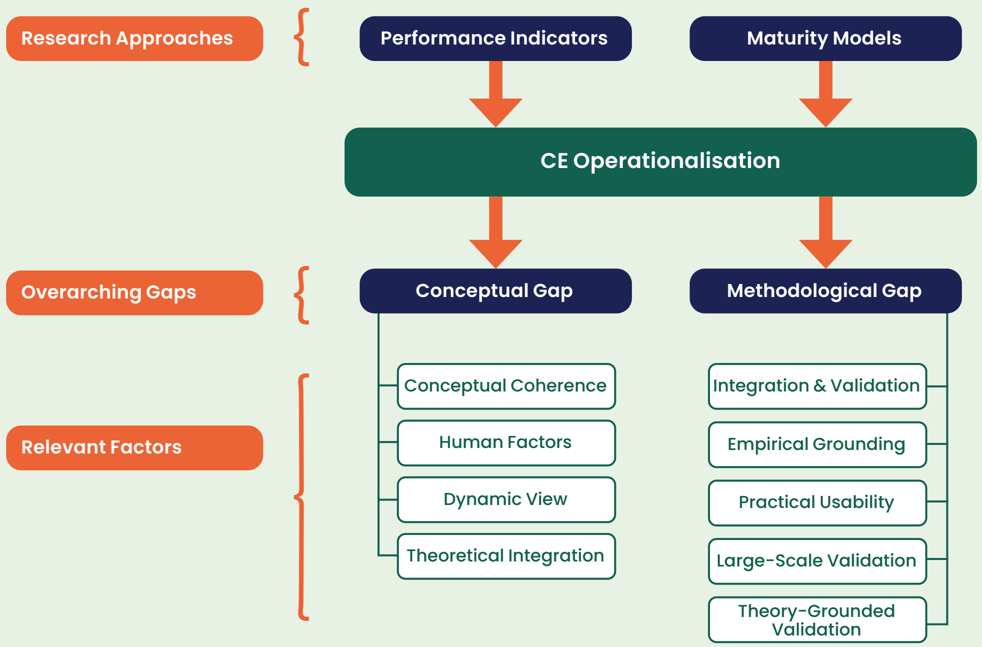
The first research approach focuses on developing indicators that measure CE Performance at the product, process, or firm levels (Bocken et al., 2025; de Arroyabe et al., 2021; Kristensen & Mosgaard, 2020; Kuzma et al., 2021; Vinante et al., 2021). These indicators are valuable tools for monitoring progress, offering quantifiable metrics that support internal assessment, and, where sufficiently standardized, enable bench-marking and communication (Kristensen & Mosgaard, 2020; Vinante et al., 2021).

Several contributions stand out for the distinctive way they advance the field. Vinante et al. (2021) introduce a value-chain-based framework that strengthens conceptual coherence by systematically organizing fragmented CE indicators into a coherent classification. As they note: “By means of a systematic literature review, the work gathers insights from 130 documents … and organizes them according to a new circular Value Chain framework, articulated into 23 categories” (Vinante et al., 2021, p. 6).

This approach reduces conceptual ambiguity and clarifies how different CE metrics relate to firm-level functions. Similarly, Bocken et al. (2025) enhance broader validation by conducting the first large-scale survey among senior leaders of multinational corporations, systematically mapping the implementation of circular strategies across geographies and sectors. They emphasize: "This study is the first large-scale study to assess the degree of CE implementation through a large-scale survey with corporations, taking into account the key circular resource strategies of Narrow, Slow, Close, and Regenerate" (Bocken et al., 2025, p. 8).

Their findings significantly enrich the empirical grounding and practical relevance of CE assessment. And finally, de Arroyabe et al. (2021) make a distinctive contribution by empirically testing the role of organizational capabilities in driving CE outcomes. Drawing on the dynamic capabilities perspective, they use survey data from 870 European firms to demonstrate that competences, standards, and information channels all have significant and positive effects on the development of CE-related products and processes. As they conclude: "Our findings provide empirical evidence that competences, standards and information channels each exert a significant and positive effect on the development of CE-related products and processes" (de Arroyabe et al., 2021, p. 15). This large-scale validation strengthens the theoretical integration of CE research with organizational capability theory and underscores the critical role of firm-level capabilities in enabling the circular transition.

Figure 1: Research Gaps



Nevertheless, indicator-based approaches tend to focus on static measurements and often overlook deeper organizational dynamics such as culture, learning, or maturity progression (dynamic view) (Kristensen & Mosgaard, 2020; Kuzma et al., 2021). While there has been some progress in improving conceptual coherence, these approaches generally pay limited attention to human and behavioral aspects (human factors), provide little insight into how circular capabilities develop over time (dynamic view), and rarely establish connections with broader theoretical perspectives that could strengthen their conceptual foundations (theoretical integration) (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Vinante et al., 2021). As a result, their contribution to an integrated understanding of CE Performance remains limited.
In this dissertation, circular capabilities are defined as firm-level abilities that enable the implementation and scaling of CE principles through the reconfiguration of resources, processes, and business models, in line with the dynamic capabilities theory (Eisenhardt & Martin, 2000; Teece, 2007). While prior literature also refers to CE capabilities (Bocken et al., 2025; de Arroyabe et al., 2021), both terms are treated as interchangeable; we consistently adopt the term circular capabilities.

The second research approach focuses on CE MMs, which offer structured maturity frameworks to evaluate how firms progress in implementing CE principles (Julkovski et al., 2023; Kayikci et al., 2022; Pigosso & McAloone, 2021; Sacco et al., 2021; Sehnem et al., 2020; Uhrenholt et al., 2022). These frameworks generally pay more attention to conceptual foundations. For example, Uhrenholt et al. (2022) offer theoretical depth by grounding their MM in Resource-Based View (RBV) and a cumulative capabilities perspective. As they explain, their framework “creates a transparent overview of the CE from organizational, technological, and business perspectives … allowing organizations to develop their circular activities accordingly” (Uhrenholt et al., 2022, p. 2).
Similarly, Kayikci et al. (2022) adopt a systems perspective and combine CE and Industry 4.0 (I4.0) principles in readiness and an MM tailored to Small and Medium Enterprises (SMEs). They highlight the importance of an integrated approach: “This study holistically addresses the issues … and enables SMEs to prepare and invest in circular principles with I4.0 technologies, which enable the achievement of smarter and more circular supply chains” (Kayikci et al., 2022, p. 377).

A notable example of practical usability is the MATChE model developed by Pigosso and McAloone (2021), which supports over 330 manufacturing companies across 38 countries. The tool offers benchmarking, gap analysis, and transition planning.
The authors state: “The resulting web-based platform enables a self-assessment of manufacturing companies’ readiness to transition to CE … and supports the development of transition paths with CE-related tools, methods and approaches” (Pigosso & McAloone, 2021, p. 346).

Together, these studies suggest that readiness and maturity should not be treated as equivalent. Readiness-oriented approaches primarily assess whether firms are prepared to initiate circular practices, whereas maturity-oriented approaches assess how firms progressively develop and integrate circular capabilities over time (Bressanelli & Saccani, 2025).

Despite their valuable contributions, CE MMs face methodological limitations. Although they increasingly integrate conceptual depth and provide MMs for assessing circular maturity, few have undergone systematic validation in diverse organizational contexts (integration & validation) (Sehnem et al., 2020). Most remain based on limited or qualitative evidence, with only partial empirical grounding (Julkovski et al., 2023), and their practical usability is often constrained by complexity or lack of contextual adaptability (Kayikci et al., 2022). Moreover, few studies have systematically validated how maturity dimensions relate to firm-level performance using theory-driven, large-scale empirical methods (Uhrenholt et al., 2022). As a result, the methodological robustness and generalizability of current MMs remain limited.

Table 2 synthesizes a selection of the exemplar studies from both research approaches and clearly shows the two research gaps identified in the reviewed studies. The table maps the diverse contributions across nine interrelated factors from Figure 1 that collectively shape the robustness of the CE evaluation. This overview illustrates how different studies address distinct factors relating to two overarching gaps, conceptual and methodological, each offering partial but valuable insights. Notably, none of the exemplar studies offers a theory-grounded validation of circular maturity or CE performance frameworks. Although some adopt theory or empirical methods, few integrate both. This underscores the relevance of our contribution, which directly addresses this gap through a Design Science (DS) approach rooted in capability theory. The factors are tightly intertwined: weaknesses in conceptual design often undermine methodological rigor, and vice versa (Eisenhardt, 1989; Gregor & Hevner, 2013). This interdependence creates what can be described as a “Gordian knot” in CE research, a set of intertwined challenges that hinders progress towards coherent, validated maturity and assessment frameworks.

Although progress has been made on individual factors, no single study addresses all nine in an integrated way. However, this complexity is not a failure; it reflects the natural condition of a field in transition, where knowledge evolves through fragmented iterative processes, not linear accumulation (Allen & Varga, 2006). Rather than viewing fragmentation as a weakness, this research considers the diversity of perspectives as a valuable reservoir of insights and potential. The following section develops this integrative stance through the metaphor of Noah’s Ark.

Table 2: Key Literature Contributions Across Exemplar Studies, Grouped by Research Approach (chronological order)

	Study	**Conceptual Gap**				**Methodological Gap**				
		conceptual coherence	human factors	dynamic view	theoretical integration	integration & validation	empirical grounding	practical usability	large-scale validation	theory-grounded validation
Performance Indicators	Kristensen and Mosgaard (2020)						✓			
	Kuzma et al. (2021)						✓			
	Vinante et al. (2021)	✓					✓	✓		
	de Arroyabe et al. (2021)	✓	✓	✓	✓	✓	✓	✓	✓	
	Bocken et al. (2025)						✓	✓	✓	
Maturity Models	Sehnem et al. (2020)	✓	✓	✓		✓	✓	✓		
	Sacco et al. (2021)	✓								
	Pigosso and McAloone (2021)	✓	✓	✓		✓	✓	✓	✓	
	Uhrenholt et al. (2022)	✓	✓	✓	✓					
	Kayikci et al. (2022)	✓	✓	✓	✓	✓	✓			
	Julkovski et al. (2023)	✓		✓	✓	✓	✓	✓		

Note: *A ✓ indicates that the study explicitly addresses the corresponding factor.*

Our review of the literature systematically reveals two overarching research gaps. First, a conceptual gap, as existing studies tend to address dimensions, indicators, maturity stages, and capabilities in a fragmented rather than integrated way. Second, a methodological gap, as existing approaches are only rarely developed and validated through a theory-based, iterative, and empirically robust research process. These gaps are a guide for defining the central research problem addressed in this dissertation and form the foundation for this study's research objectives and design.

1.3 Noah's Ark: Systemic Thinking in a World of Limits

Building on the above contributions, this study adopts a systems thinking perspective to integrate diverse approaches in CE Performance research. Rather than discard existing models and indicators, this work recognizes them as essential building blocks. Like Noah's Ark in the Bible, bringing together diverse life forms to survive turbulent conditions, this research consolidates conceptual fragments into a coherent whole by explicitly integrating and adapting core elements from existing CE assessment and maturity approaches.

To support this synthesis, Figure 2 shows the intellectual lineage underpinning the Circular Maturity Tool (CMT) developed in this research. It shows how key studies, addressing specific perspectives of circular maturity and / or indicators, inform, inspire, or complement each other. This genealogical overview underscores the systematic objective of this research: to construct an integrative framework that brings together validated in-sights across research traditions rather than supplant them. A detailed explanation of the relationships and study interconnections shown in Figure 2 is provided in Appendix B. Importantly, this synthesis is not merely conceptual but also guides the design of the CMT. Rather than introducing entirely new elements, the framework builds on and recombines core components developed in earlier studies. Specifically, indicator-based studies inform the identification and structuring of relevant circularity dimensions (Kristensen & Mosgaard, 2020; Vinante et al., 2021), existing MMs contribute the staged progression logic (Becker et al., 2009; de Bruin et al., 2005), and capability-oriented approaches provide the foundation for operationalizing maturity in terms of organizational capabilities (de Arroyabe et al., 2021; Uhrenholt et al., 2022). In addition, readiness-oriented tools inform the broad organizational scope of assessment (Pigosso & McAloone, 2021), which is extended in this study from initial preparedness to staged capability development over time. Together with Table 2, Figure 2 illustrates both the richness and fragmentation of current circular maturity and indicator research.

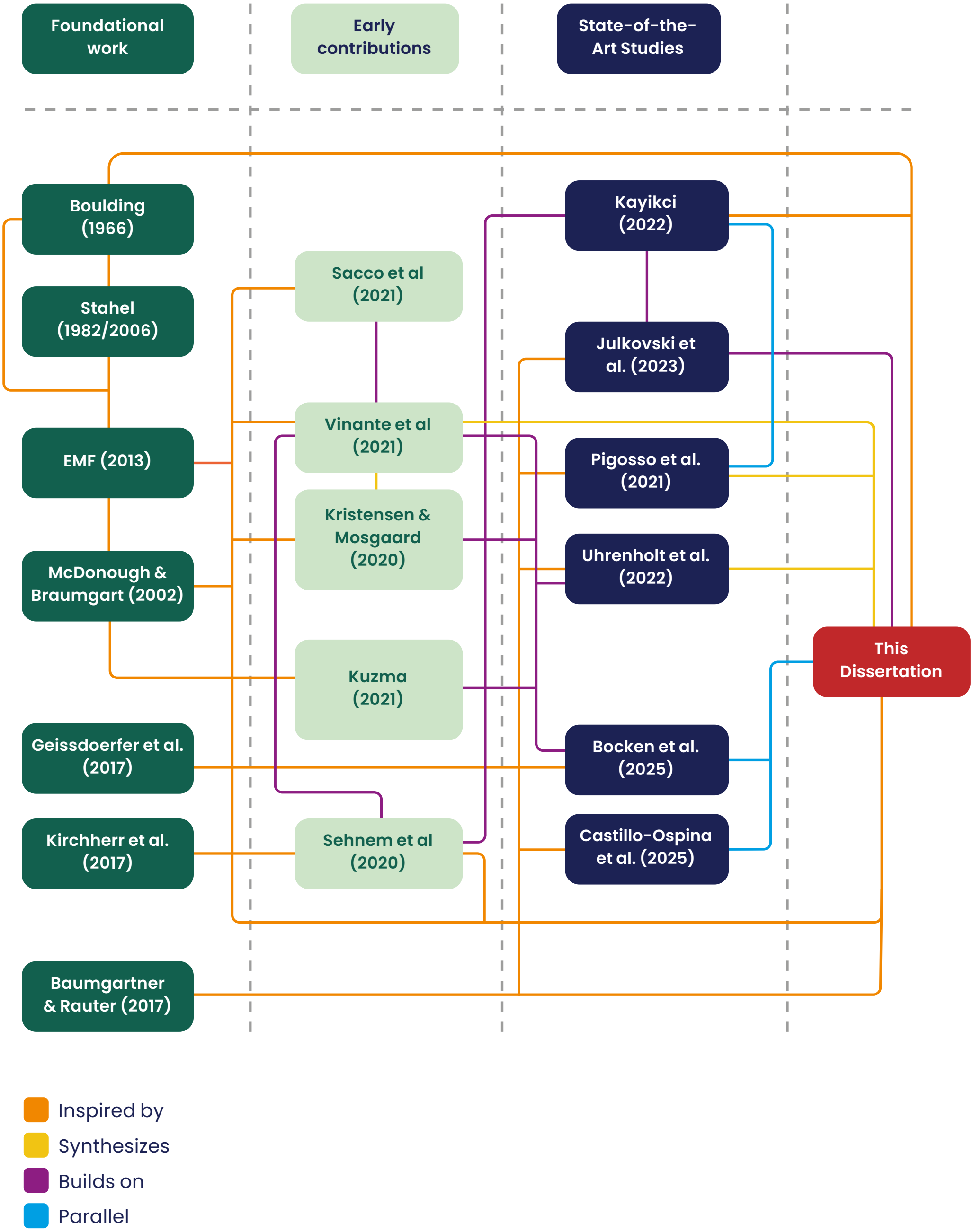
Compared with existing circular maturity and readiness approaches, the CMT shares several core characteristics, however, differs in important ways. Similar to prior MMs, it adopts a staged view of organizational development, aiming to support the diagnosis and improvement of organizational practices (Becker et al., 2009; de Bruin et al., 2005; Pöppelbuß & Röglinger, 2011). Like existing circular maturity approaches, the CMT incorporates multiple organizational dimensions to capture different aspects of circularity (Kayikci et al., 2022; Sehnem et al., 2020; Uhrenholt et al., 2022).

Nevertheless, the CMT differs from most existing approaches in four ways. First, it explicitly integrates insights from indicator-based and maturity-based traditions, which are often treated separately in prior research (Cayzer et al., 2017; Elia et al., 2017; Parchomenko et al., 2019; Vinante et al., 2021). Second, it conceptualizes circular maturity as a capability-based and multidimensional construct at the firm level, rather than focusing primarily on readiness, single functions, or isolated circular practices (Sehnem et al., 2020; Uhrenholt et al., 2022). Third, it links organizational dimensions, maturity levels, and operationalized capabilities within one coherent assessment architecture, addressing the fragmentation identified in prior circular maturity research (Lindgreen et al., 2020; Parchomenko et al., 2019). Fourth, it is developed and validated through an iterative DS process that combines literature synthesis, qualitative inquiry, expert validation, beta testing, and large-scale empirical analysis (Hevner et al., 2004; Peffers et al., 2007).

The idea that economic activity must respect ecological boundaries has deep intellectual roots. In his seminal essay *The Economics of the Coming Spaceship Earth*, Kenneth Boulding (1966) contrasted the "cowboy economy," characterized by open, exploitative resource use, with the "spaceship economy," which recognizes planetary limits and calls for the implementation of closed-loop systems to maintain material flows within ecological boundaries (Boulding, 1966). This notion of the Earth as a bounded system, comparable to the Ark that preserves life within finite conditions, illustrates the core tenets of systems thinking: interdependence, constraint, feedback, and adaptive governance. This perspective was further developed by Walter Stahel, who introduced the concept of the "performance economy," emphasizing longevity, reuse, and regeneration (Stahel, 2016). Organizations like the Ellen MacArthur Foundation have since positioned CE as a transformative model that aims to decouple growth from resource use while improving the system's resilience (Ellen MacArthur Foundation, 2013). Among these contributions, CE emerges not merely as a technical fix, but as a systemic innovation that challenges dominant assumptions about how firms interact with ecological and institutional systems and has the potential to drive a paradigm shift in economic thinking.

To analyze circular maturity at the firm level, this research adopts systems thinking as a guiding perspective. This lens implies moving beyond static or traditional models of progress to view firms as embedded in dynamic, multi-level systems. Circular transitions are thus seen as emergent, non-linear processes shaped by feedback loops, institutional context, and the evolution of dynamic capabilities (Baxter & Sommerville, 2011; Meadows, 2008).

Figure 2: The CMT's Intellectual Lineage: Synthesizing Maturity Models and Indicator Frameworks



To avoid conceptual ambiguity, this dissertation defines circular maturity as the extent to which a firm has developed and integrated circular capabilities across organizational dimensions in a structured and progressive manner, enabling it to systematically advance its circular transition and improve CE Performance. Thus, circular maturity is not conceptualized as a one-off score or a fixed end-state, but as a multidimensional, dynamic, capability-based construct at the firm level that reflects the gradual development of organizational capabilities required for circular transformation (Sehnem et al., 2020; Vinante et al., 2021). This implies that maturity is expressed through the configuration and evolution of capabilities across organizational dimensions and can be represented through staged maturity levels that capture progressive capability development (Becker et al., 2009; de Bruin et al., 2005; Pöppelbuß & Röglinger, 2011). While prior literature also refers to CE maturity, both terms are interchangeable; however, this dissertation adopts the term circular maturity for consistency.

Circularity differs conceptually from circular maturity because it refers to observable outcomes, while circular maturity refers to the underlying capability development that enables firms to achieve and scale such outcomes over time (Kristensen & Mosgaard, 2020). In addition, circular maturity is conceptually distinct from readiness-oriented approaches, which primarily assess firms' initial preparedness to engage in circular practices rather than their staged capability development over time (Bressanelli & Saccani, 2025).

1.4 Research Objectives

Building on the systems thinking perspective outlined above, this research responds to the conceptual and methodological gaps identified in the preceding sections. More specifically, it addresses the lack of an integrated firm-level circular maturity perspective and the limited use of theory-grounded and empirically robust validation approaches in existing circular maturity research. Our research develops a coherent and empirically grounded MM that builds on existing CE MMs, CE indicator frameworks, and other CE literature, while addressing the fragmentation identified earlier. To fulfill these aims, the overall goal of this research is:

> ***To design, integrate, and validate a MM that supports firms in assessing and developing their capabilities to advance circular maturity.***

Integration in this context refers to the structured combination of conceptual elements in existing models and indicators, empirical insights from firm-level applications, and theoretical constructs from capability-based organizational theory.

This overall goal is operationalized in the methodological research question introduced in Chapter 2 and involves pursuing three specific objectives:

1. **Conceptual synthesis and model development (Chapter 3 – Building the Alpha Version)**: Identify, consolidate, and integrate key components from existing MMs, indicator frameworks, and the CE literature into a coherent MM grounded in systems thinking and organizational capability theory.
2. **Model application and refinement (Chapter 4 – Beta Version Building & Evaluation)**: To iteratively apply, evaluate, and refine the CE MM across diverse firms and sectoral contexts, ensuring its practical usability, contextual relevance, and empirical robustness.
3. **Capability analysis and theory-building (Chapter 5 – Validating Circular Capabilities for CE Performance)**: Investigate how specific organizational capabilities relate to circular maturity and performance outcomes, using RBV and dynamic capabilities theory, and validating these relationships through structural equation modeling.

1.5 Research Contributions and Dissertation Structure

We conclude the introduction by summarizing this dissertation's contributions and out-lining its structure. Building on the identified research gaps and objectives, this study contributes to the literature and practice of circular economy transitions in three complementary ways: practical, conceptual, and methodological.

Practical Contribution

The key contributions of this research are the design and validation of the CMT. This structured MM enables firms to assess their circular capabilities, identify priority areas, and guide their transition to more circular practices. The CMT responds to practical needs by offering clarity and usability, as well as academic needs by consolidating and validating fragmented approaches to circular maturity.

Conceptual Contribution

Conceptually, the research advances the field by addressing four key factors: conceptual coherence, human factors, dynamic view, and theoretical integration. The CMT integrates insights from RBV and dynamic capabilities theory, both in its conceptual structure, by framing circular maturity as a function of organizational capabilities, and in its empirical validation, which tests capability–performance linkages using structural equation modeling.

Methodological Contribution

Methodologically, the research contributes by addressing five known shortcomings in existing models: integration & validation, empirical grounding, practical usability, large-scale validation, and theory-grounded validation. It does so by integrating multiple research methods, including literature synthesis, qualitative inquiry, expert validation, and quantitative analysis, within a coherent and iterative research design. The result is a validated, theory-informed, and context-sensitive MM for evaluating circular maturity.

Positioning and Structure

This dissertation follows a paper-based format, ensuring that individual chapters can be read and understood independently, while enabling the dissemination of results through peer-reviewed journal publications. At the same time, the dissertation is grounded in a single, coherent research trajectory. Chapters 3–4 collectively form an integrated study focused on the development, refinement, and evaluation of the CMT. Chapter 5 provides additional large-scale validation of the relationship between circular capabilities and performance outcomes. Note that a limited degree of conceptual overlap is intentionally retained to ensure standalone readability of individual chapters, while avoiding duplication of the overarching contextualization.

The dissertation is structured as follows. Chapter 2 presents the methodological foundation. Chapters 3 and 4 cover the development and iterative evaluation of the artifact. Chapter 5 extends this work through large-scale validation. Finally, Chapter 6 synthesizes the overall findings and reflects on the contributions, limitations, and directions for future research.

1.6 Dissemination

To ensure both academic rigor and practical relevance, this research followed a dual dissemination strategy. The results were shared through peer-reviewed publications and practitioner-oriented events, allowing for iterative refinement of the CMT.

From an academic perspective, journal articles and conference papers provided a vehicle to operationalize and validate the CMT, ensuring methodological transparency and theoretical contribution. From a practical perspective, workshops, master classes, and presentations to firms and policy actors enabled feedback loops that improved usability and contextual fit.
This combination of scholarly and practice-based dissemination ensured that the CMT was continually refined for both scientific robustness and practical usability.

In total, dissemination included six publications, over twenty-five conference contributions, and more than fifteen practitioner workshops, seminars, and policy engagements. A complete overview of dissemination activities is provided in Table 33, in Appendix C.

1.7 Authors' Contributions

This research is the result of extensive collaborative efforts with multiple co-authors. In line with academic conventions for co-authored work, Table 3 provides an overview of all the authors' contributions to the constituent chapters, covering intellectual input, conceptual development, data analysis, and manuscript preparation.

Table 3: Overview of Authorship Contributions per Chapter

	Arjen Wierikx	Néomie Raassens	Alex Alblas	Pascal Ravesteijn	Guido Ongena
Chapter 1: Introduction					
Manuscript drafting	✓				
Review and feedback	✓	✓	✓	✓	
Chapter 2: Research Process					
Conceptual design	✓	✓	✓		
Literature review	✓				
Manuscript drafting	✓				
Review and feedback	✓	✓	✓	✓	
Chapter 3: Building the Alpha Version					
Conceptual design	✓	✓	✓	✓	
Literature review	✓	✓	✓	✓	
Data collection	✓				
Data preparation	✓				
Data analysis	✓				
Results interpretation	✓	✓	✓	✓	
Manuscript drafting	✓				
Review and feedback	✓	✓	✓	✓	

Table 3: Overview of Authorship Contributions per Chapter – Continued

	Arjen Wierikx	Néomie Raassens	Alex Alblas	Pascal Ravesteijn	Guido Ongena
Chapter 4: Beta Version Building and Evaluation					
Conceptual design	✓	✓	✓	✓	
Literature review	✓		✓		
Data collection	✓				
Data preparation	✓				
Data analysis	✓				
Results interpretation	✓	✓	✓	✓	
Manuscript drafting	✓				
Review and feedback	✓	✓	✓	✓	
Chapter 5: Validating Circular Capabilities for CE Performance					
Conceptual design	✓			✓	✓
Literature review	✓		✓		✓
Data collection	✓				
Data preparation	✓				
Data analysis	✓				✓
Results interpretation	✓				✓
Manuscript drafting	✓				✓
Review and feedback	✓	✓	✓	✓	✓
Chapter 6: Discussion & Conclusion					
Manuscript drafting	✓				
Review and feedback	✓	✓	✓	✓	✓

CHAPTER

2

Research Process

2. Research Process

Note: Parts of the text in this chapter are also included in a manuscript currently under review for publication in Technovation (Wierikx, Raassens, et al., 2026).

2.1 Chapter Overview

This chapter outlines our overarching research approach, focusing on the development and validation of a Circular Maturity Tool (CMT) for firms transitioning to a Circular Economy (CE). As such, this chapter lays the foundation for contextualizing and justifying the multi-step design approach throughout the research. Our research is grounded in Design Science (DS) methodology, which is particularly well-suited for developing relevant artifacts in practice with scientific rigor (Hevner et al., 2004; Peffers et al., 2007). Combined with the Maturity Model (MM) development principles, DS provides a robust methodological framework for structuring and guiding the creation of diagnostic tools that help firms assess and enhance their CE Performance (Becker et al., 2009; de Bruin et al., 2005; Hevner et al., 2004).

The methodology presented here forms the starting point of an integrated DS study that is further developed in Chapters 3,4 and 5. While each of these chapters is a standalone contribution, together they constitute a single coherent research process. Chapter 3 presents the initial artifact development (v1), while Chapter 4 extends this with an alpha evaluation, beta building (v2) and evaluation, and further refinement of the artifact (v3). Chapter 5 complements this DS trajectory by providing a separate empirical validation of the broader relationships underlying the dissertation, thereby extending the overall methodological scope beyond artifact development alone.

In addition to methodological grounding, this chapter clarifies how the research ensures theoretical rigor, empirical relevance, and practical usability. By aligning DS phases with MM development stages, and embedding the Design Science Validity Framework (DSVF), our approach ensures that the resulting artifact, the CMT, is not only conceptually sound, but also applicable across diverse organizational contexts.

2.2 Research Question

Rather than reiterating the broader contextualisation, this chapter focuses specifically on the study's methodological design. Building on the research objectives outlined in Chapter 1, it details our approach to develop and validate the CMT.

The study adopts a DS approach to guide the systematic design, development, and evaluation of the artifact through iterative design and validation cycles. The central research question guiding this chapter is:

> ***How can firms systematically assess and develop their circular capabilities to advance circular maturity using a standardized artifact?***

This question is based on the dissertation-level objective introduced in Chapter 1, focusing specifically on the artifact as the central mechanism for addressing the identified research problem.

2.3 Design Science as the Overarching Research Approach

The identified research gaps, which are both conceptual and methodological in nature, require a research approach that not only explains existing phenomena but also supports the creation and iterative refinement of practical solutions. Traditional theory-driven models, which primarily focus on explanation or classification, offer limited support for such integrative, solution-oriented efforts. As argued by Gregor and Hevner (2013) and Van Aken (2004), such challenges are better addressed through design-oriented method-ologies that integrate knowledge, support iteration, and produce actionable solutions. Consequently, this research adopts DS as the overarching research approach to structures the entire dissertation. Alternative methodological approaches were considered, including survey-based research, case study research, and action research.

To guide the selection of an appropriate research approach, we applied three criteria, based on MM development research and broader design-oriented research: (i) the ability to support the development of a purposeful artifact, (ii) the capacity for iterative refinement through multiple design cycles, and (iii) the possibility to combine practical relevance with rigorous evaluation (Becker et al., 2009; de Bruin et al., 2005; Hevner et al., 2004).

Survey-based research primarily supports testing relationships between predefined constructs and is therefore less suitable for developing novel artifacts (Pinsonneault & Kraemer, 1993). Case study research enables in-depth contextual understanding but typically focuses on explanation and theory building rather than the systematic design and validation of solutions (Eisenhardt, 1989; Yin, 2018). Action research supports intervention in real-world settings and iterative learning; however, it often places less emphasis on the development of generalizable artifacts and formalized evaluation procedures (Baskerville & Wood-Harper, 1996; Davison et al., 2004).

While both these approaches offer valuable insights for specific research purposes, they are less aligned with the combined requirements of artifact development, iterative refinement, and rigorous evaluation central to this research.
Given these criteria, DS was selected as the most appropriate approach, as it explicitly integrates artifact development, iterative refinement, and rigorous evaluation within a coherent methodological framework (Hevner et al., 2004; Peffers et al., 2007).

DS is particularly suitable for this study as the domain of circular maturity is both theoretically fragmented and practically urgent, characterized by a proliferation of models with limited empirical validation and theoretical integration (Hevner et al., 2004). DS combines the creation of purposeful artifacts with the generation of academic insights, enabling researchers to structure complex problem spaces while delivering usable solutions (Hevner et al., 2004; Peffers et al., 2007). The field of circular maturity exemplifies such a domain: it is ambitious and fast-moving, yet fragmented in terms of models, empirical validation, and theoretical synthesis.

The DS methodology aligns closely with the systems thinking perspective adopted in this research. Whereas systems thinking provides a lens to understand firms as embedded in dynamic, multi-level environments (Meadows, 2008; Senge, 1990), DS offers a structured process for developing and validating assessment artifacts that operate within such environments (Gregor & Hevner, 2013; Hevner et al., 2004).

Within this dissertation, the development of the CMT follows a full DS cycle, including problem identification, definition of objectives, design and development, demonstration, evaluation, and communication. This Chapter outlines the research design and methodological foundation, Chapter 3 presents the development of the initial artifact (v1), and Chapter 4 reports its evaluation and iterative refinement through alpha and beta testing, resulting in successive versions and the final validated artifact (v3). Chapter 5 complements this process by providing a large-scale empirical analysis of the relationship between circular capabilities and performance outcomes, thereby strengthening the validation and broader applicability of the developed artifact.

2.4 Methodology

2.4.1 Integrating Design Science and Maturity Model Development

To develop the CMT as a structured yet adaptable artifact, this research adopts a DS approach, which provides a rigorous, problem-driven methodology for artifact creation, iterative refinement, and empirical validation (Peffers et al., 2007). As a research paradigm rooted in problem-solving and innovation, DS ensures that the CMT is not only theoretically sound but also actionable in real-world applications (Hevner et al., 2004). By embedding iterative design-evaluate cycles, this research ensures that the CMT evolves through multiple rounds of refinement, incorporating both empirical insights and theoretical advancements.

DSVF (Larsen et al., 2025) is used to guide validation across the development of the CMT. Specifically, it structures the evaluation using three types of validity: criterion validity, causal validity, and context validity, ensuring alignment with the CMT's intended purpose, underlying causal mechanisms, and real-world applicability.

While DS guides the systematic development of the CMT, the MM development process (de Bruin et al., 2005) provides a structured mechanism for defining progressive, hierarchical maturity levels, ensuring the model's scalability, applicability, and organizational relevance. The MM enables the CMT to systematically assess CE performance across various organizational contexts, offering a prescriptive pathway for firms to enhance their circular capabilities over time.

By aligning the six phases of DS (Peffers et al., 2007) with the six stages of MM development (de Bruin et al., 2005), this research reinforces both methodological rigor and practical applicability in the design and validation of the CMT. The problem identification & motivation phase, aligned with the scope stage ensures that the research framework (see Figure 3) addresses the identified research problem. The iterative design and development process, informed by empirical testing and expert validation, strengthens the internal validity and external applicability of the CMT. Finally, the evaluation and deployment stages ensure that the research framework is both robust and adaptable, enabling firms to systematically diagnose, benchmark, and improve their circular maturity.

2.4.2 Mapping Design Science Phases to Maturity Model Development Stages

The development of the CMT follows a structured approach that integrates DS according to Peffers et al. (2007) with MM development in line with de Bruin et al. (2005). While DS ensures rigorous development and validation, the MM structure enhances practical scalability across contexts. Although DS serves as a meta-methodological process (Collatto et al., 2018), we also apply additional research methodologies.

To provide an integrated overview of the research design, Figure 3 presents the over-arching research framework, linking the DS cycle to MM development stages and their empirical operationalization in Chapters 3 and 4.

The core DS cycle is complemented by a separate theory-driven validation stream in Chapter 5, where large-scale validation data and Partial Least Squares Structural Equation Modeling (PLS-SEM) analyses test the relationships between circular capabilities and performance outcomes.

Together, this structure reflects this study's dual contribution: designing the CMT and the empirical validation of its underlying capability-performance relationships.

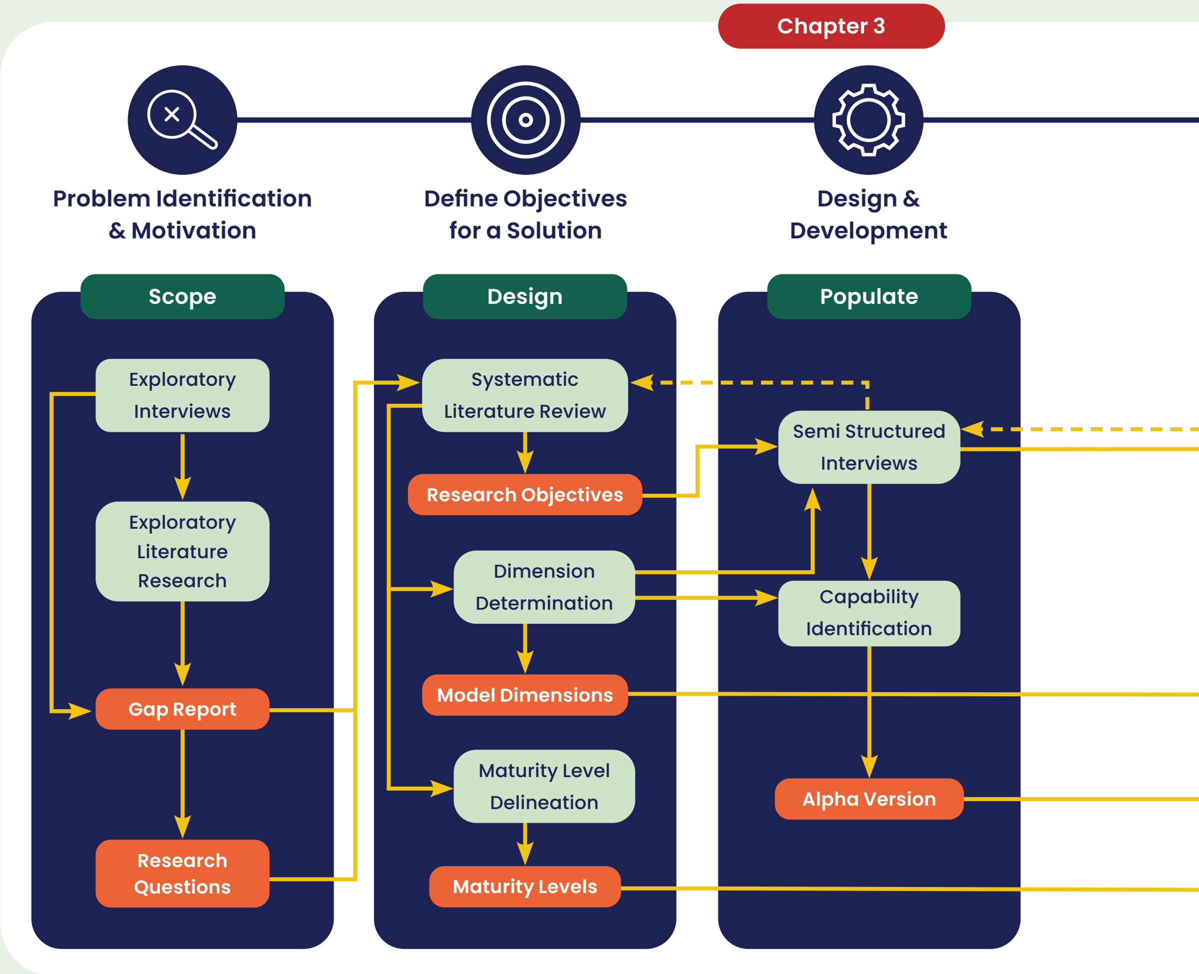
Table 4 presents a detailed mapping of the integrated DS and MM framework, including the additional methods.

To emphasize the methodological rigor of our approach, we used DSVF (Larsen et al., 2025) to guide validation across the development process. While Table 4 provides a holistic overview, Table 5 focuses specifically on how each DS phase integrates criterion, causal, or context validity. This dual structure reinforces the robustness of the CMT and underscores the novel application of DSVF within CE research. Please note: the validation activities reported in Chapter 5 fall outside the DSVF scope, as they focus on statistically testing relationships between constructs not validating the actual artifact.

The research process begins with the identification of the problem and motivation phase, aligned with the scoping stage of MM development. This phase defines the scope and purpose of the maturity tool. The problem definition establishes the relevance of a maturity-based evaluation system and highlights existing gaps in CE assessment methods.

Figure 3:

Research Framework: Integrated Design Science and Maturity Model Research Architecture



Design Science Phase
Maturity Model Stage
Research Methods
Deliverables
Final Deliverables
Visualizing Iterations

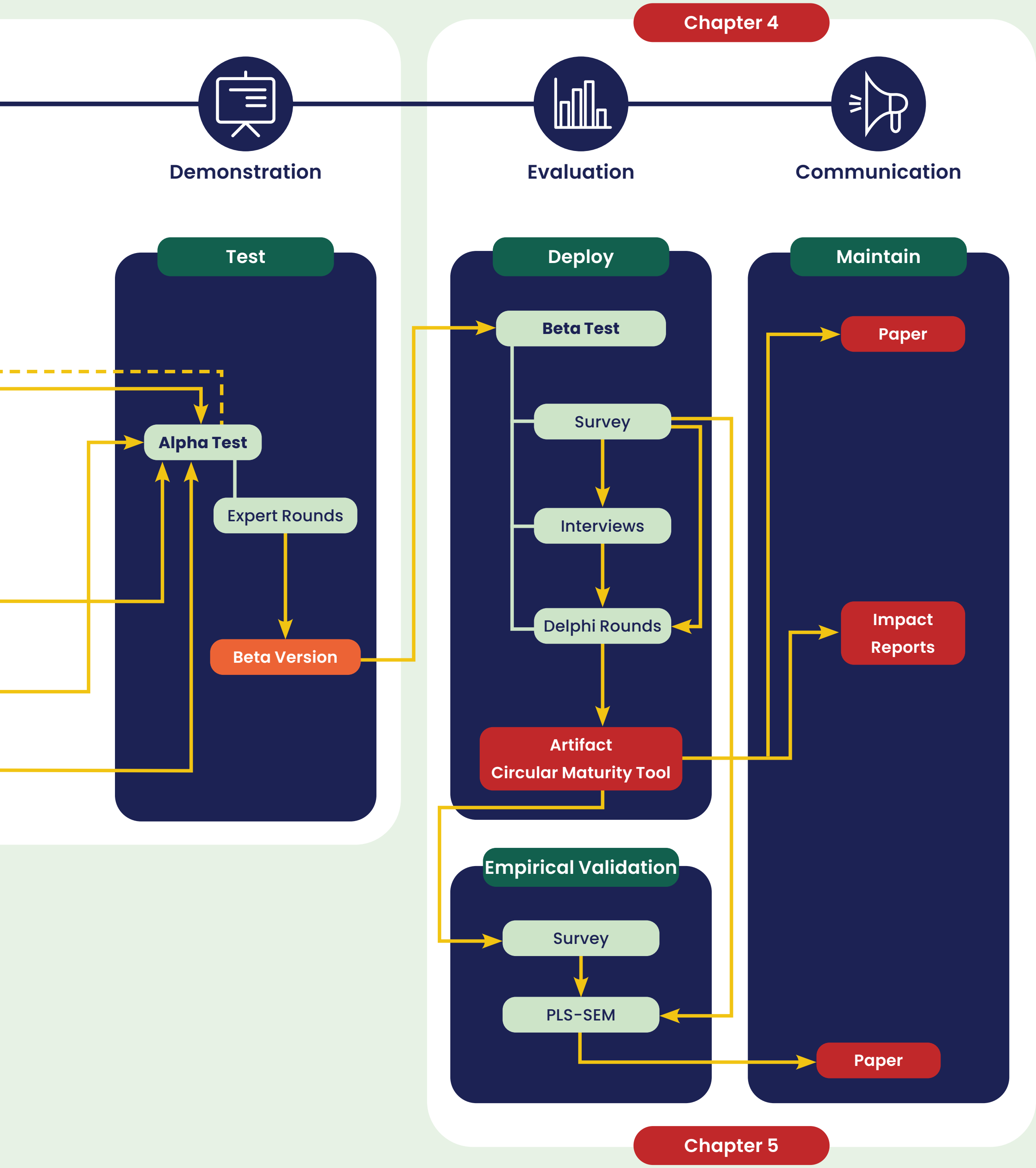

Chapter 4
Demonstration
Evaluation
Communication
Test
Alpha Test
Expert Rounds
Beta Version
Deploy
Beta Test
Survey
Interviews
Delphi Rounds
Artifact
Circular Maturity Tool
Empirical Validation
Survey
PLS-SEM
Maintain
Paper
Impact
Reports
Paper
Chapter 5

Table 4: Research Methods related to DS Phases, MM Development Stages, and Validation

Nr	DS Phase (Peffers et al., 2007)	MM Development Stage (de Bruin et al., 2005)	Research Activities (incl. Validation Larsen et al., 2025)
1	**Problem Identification & Motivation**	**Scope**	Exploratory literature search to identify the research gap, leading to the decision to apply DS combined with MM. This aligns with the Scope stage in MM development, where the CMT's purpose, domain, and target audience are defined. **Validation:** Ensured criterion validity by verifying that the problem definition aligns with real-world CE challenges.
2	**Define Objectives for a Solution**	**Design**	Systematic Literature Review (SLR) to retrieve CMT dimensions. This step ensures that the CMT is grounded in theory while addressing identified gaps. The Design phase in MM development defines the dimensions and maturity levels. **Validation:** Strengthened criterion validity by aligning dimensions with existing CE literature and expert feedback.
3	**Design & Development**	**Populate**	Conducted 54 interviews to confirm the research gap and validate dimensions using narratives and quotes. Derived capabilities for each dimension from both literature and interviews. This aligns with the Populate stage in MM development, where CMT characteristics and assessment criteria are developed. **Validation:** Applied causal validity by ensuring that maturity levels correspond to actual improvements in CE performance.

Table 4: Continued

Nr	DS Phase (Peffers et al., 2007)	MM Development Stage (de Bruin et al., 2005)	Research Activities (incl. Validation Larsen et al., 2025)
4	**Demonstration**	**Test**	Conducted an alpha test to validate the dimensions and capabilities. The Test phase in MM development ensures the CMT is evaluated in controlled settings before full deployment. **Validation:** Strengthened context validity by testing the CMT applicability in controlled environments.
5	**Evaluation**	**Deploy**	Conducted a beta test collecting data across a diverse sample of firms, and 36 additional interviews with C-level managers. Performed qualitative and quantitative analyses on the beta test results. Conducted three Delphi rounds to refine the framework. The Deploy stage in MM development ensures the framework is tested in real-world environments and refined based on empirical data. **Validation:** Addressed causal validity (via statistical testing) and context validity (via diverse firm validation).
6	**Communication**	**Maintain**	Presented and published findings. The MM maintain stage ensures the framework remains updated, scalable, and adaptable to industry developments. **Validation:** Ensured ongoing criterion validity by updating framework components based on emerging research and practical applications.

Table 5: Mapping Design Science Phases to Validity Types (Adapted from Larsen et al., 2025)

DS Phase	Validity Type	Application in CMT
Problem Identification	Citerion validity	Ensuring CMT addresses real CE challenges
Objectives Definition	Criterion validity	Aligning dimensions with CE literature
Design	Causal validity	Ensuring indicators measure firm progress
Development	Causal validity	Testing if maturity levels predict circularity
Demonstration	Context validity	Alpha test for adaptability across industries
Evaluation	Context validity	Beta test & Delphi rounds for validation

The scope stage ensures that the target audience, framework objectives, and contextual applicability are clearly defined, setting the MM foundation.

Once the problem is well defined, the objectives are determined in the define objectives for a solution phase, aligned with the design stage in MM development. Here, the research determines the core dimensions and associated capabilities of the CMT, structuring the CMT into well-defined maturity levels. This phase integrates insights from CE literature, expert consultations, and empirical observations to ensure that the CMT aligns with theoretical foundations while remaining practically relevant. The MM structured design enables firms to navigate their circular transition through progressive stages of development.

The next phase in DS, design and development, corresponds to the populate stage in MM development. In this phase, the CMT is further elaborated by defining maturity levels and populating each dimension with narrative descriptions and underlying capabilities. These elements are derived through integrating insights from the CE literature and qualitative interview findings. This phase focuses on specifying the characteristics that distinguish different maturity levels, thus shaping the conceptual structure of the CMT prior to formal testing.

Following the initial development of the CMT, the demonstration phase in DS aligns with the test stage in MM development. The CMT udergoes empirical testing, expert reviews, and pilot applications in selected firms. This phase validates the CMT's effectiveness in assessing circular maturity and identifying improvement areas. Testing ensures that the CMT accurately reflects real-world organizational challenges and provides actionable insights for firms seeking to enhance their circular practices. Feedback from this phase is incorporated in iterative refinements, improving the CMT's clarity, usability, and reliability.

The next phase, evaluation, directly maps onto the deployment stage in MM development. Here, the CMT is implemented in practice across firms to assess its effectiveness in guiding circular transitions. The deployment stage evaluates whether firms can use the MM to diagnose their current CE Performance and explore its potential to support benchmarking and strategic improvement planning. This stage not only validates the CMT's practical applicability but also highlights areas for further refinement to enhance its impact.

Finally, the communication phase in DS corresponds to the maintain stage in MM development. The findings from the research process are disseminated through academic publications, industry reports, and policy recommendations to ensure widespread adoption and further scholarly engagement. The CMT remains dynamic, continuously updated to reflect advancements in CE research, regulatory changes, and industry best practices. The maintain stage ensures that the CMT remains relevant, scalable, and adaptable to evolving sustainability challenges.

2.4.3 Research Protocols and Methodological Transparency

Building on the research framework presented above, this section details how methodological rigor, transparency, and replicability are ensured through explicitly defined research protocols. These protocols specify how each research activity within the DS process was operationalized. While the research activities are described in Chapters 3, 4 and 5, this section provides a consolidated overview of how each method was operationalized.

For each research activity, we focus on key aspects of methodological transparency and replicability across the research process. These aspects include (i) the underlying data sources, (ii) the criteria for case and respondent selection, (iii) the procedures for data collection, (iv) the analytical approaches, and (v) the strategies to validate the findings. Together, these dimensions provide a structured lens for assessing the transparency and reproducibility of the research process. Table 6 provides an explicit overview of the protocols underlying each research method, including data collection, selection procedures, and analysis approaches. Detailed materials are described in the respective chapters and are further supported by supplementary materials, including (online) appendices. Together, these materials ensure that the full research process can be traced, evaluated, and, where relevant, replicated by other researchers, strengthening the methodological rigor and reproducibility of the CMT's development.

Table 6: Overview of Research Protocols Ensuring Transparency and Replicability

Method	Key Elements	Protocol Description
Systematic Literature Review (SLR)	Search strategy, selection criteria, screening	Conducted using predefined search strings and databases. Inclusion and exclusion criteria were applied (see Section 3.2.2, Tables 8–10). Articles were screened in multiple stages (title, abstract, full-text), followed by structured data extraction and synthesis procedures.
Semi-structured Interviews	Sampling, interview guide, data collection, analysis	Participants were selected using purposive sampling based on expertise in CE practices. Interviews followed a predefined guide, were recorded and transcribed, and analysed using thematic coding procedures. Section 3.2.3 describes the interviews for building the alpha version. Section 4.3.2 describes the in-depth interviews following survey completion with the beta version. An overview of the interviews is in the online appendices (Appendix L #15).
Alpha Evaluation	Expert selection, evaluation criteria, feedback process	Experts were selected based on domain knowledge. The evaluation followed predefined criteria (e.g., relevance, clarity, completeness). Structured feedback was collected and used for iterative refinement. The alpha (v1) method is described in Section 4.2.1, and the findings in Section 4.3.1.
Beta Testing	Survey design, sampling, data collection, analysis	Data was collected using the beta version (v2) survey across a diverse sample of firms (see Section 4.2.2 for the method and Section 4.3.2 for the findings). Quantitative analysis and measurement validation procedures are documented in Appendix G.
Delphi Study	Iterative rounds, consensus criteria	Multiple Delphi rounds were conducted with expert participants. Structured feedback and predefined consensus criteria were applied across multiple rounds to refine CMT components (Appendix I/J).
Theory Driven Quantitative Validation	Measurement instrument, sampling, missing data treatment, measurement validation, structural CMT assessment	A survey-based quantitative validation study used the final version of the instrument (v3) to test the conceptual CMT and hypotheses. Data was collected from managers and decision-makers using a mixed sampling strategy combining purposive and open-access recruitment. Missing data was assessed, using Expectation–Maximization imputation where appropriate. Reliability, convergent validity, and discriminant validity were evaluated following established PLS-SEM procedures, then the structural CMT was assessed. Ethical safeguards and statistical checks for common method bias were also applied. The method is described in Section 5.4, and the results in Section 5.5.

2.5 Discussion and Conclusions

This chapter outlined the overarching research process to develop, validate, and implement the CMT. By integrating DS and MM development in our research framework, we provided a structured foundation for the conceptualization and refinement of the artifact. This methodology enabled a rigorous and iterative approach to artifact design, rooted in both academic literature and real-world practice.

2.5.1 Synthesis of Methodological Contributions

The chapter demonstrated how the six DS phases (Peffers et al., 2007) were mapped onto the six MM development stages (de Bruin et al., 2005), thus ensuring a logical and sequential alignment between problem definition, design activities, and validation protocols. This mapping enabled the CMT to evolve systematically from a research framework to a validated, practically deployable tool. By incorporating empirical methods such as a systematic literature review, semi-structured interviews, expert consultations, and Delphi rounds, the research process maintained methodological triangulation and inclusion of stakeholders.

Furthermore, the use of DSVF (Larsen et al., 2025) improved the transparency and robustness of the validation logic. DSVF's emphasis on criterion, causal, and context validity helped to ensure that the artifact was not only theoretically coherent but also practically effective across different organizational settings. This multidimensional validation strategy reinforces the generalizability and scalability of the CMT.

2.5.2 Positioning Within the Dissertation

Although this chapter does not present empirical findings, it has a critical bridging function. It connects the overarching research objectives introduced in Chapter 1 to the empirical artifact development described in Chapters 3 and 4. Moreover, it introduces key methodological commitments that also underpin the work in Chapter 5, particularly the emphasis on real-world testing, expert feedback, and context-sensitive application.

This chapter also clarifies how various validation and methodological tools are used in our research. The CMT's alpha development and initial validation, outlined in Chapter 3, are a direct consequence of the DS logic. Similarly, the focus in Chapter 4 on beta testing and empirical evaluation is based on the structured evaluation principles introduced in this chapter. Chapter 5 draws on this same methodological foundation but extends it to a distinct research context. In contrast to Chapters 3 and 4, which emphasize artifact development and empirical testing through practitioner engagement, Chapter 5 applies a theory-guided empirical validation strategy.

It employs a quantitative approach to assess the structural robustness and theoretical alignment of the CMT with distinct empirical data. This distinction not only demonstrates the conceptual foundation of CMT beyond practice-based validation, but also highlights its generalizability in academic research contexts. As such, Chapter 5 complements the previous chapters by providing a more abstract and analytically rigorous examination of the artifact's validity.

CHAPTER

3

Building the Alpha Version

3. Building the Alpha Version

Note: Except for the Introduction, the first subsections of Methodology, Discussion, and Conclusions, the content of this chapter is part of a manuscript currently under review for publication in Technovation (Wierikx, Raassens, et al., 2026).

3.1 Introduction

This chapter builds on the research framework and Design Science (DS) approach introduced in Chapters 1 and 2. While Chapter 1 established the conceptual foundation and research gaps, and Chapter 2 outlined the methodological approach, the present chapter focuses on the development of the alpha version (v1) of the artifact.

Within the broader DS cycle, this chapter covers the initial three steps: problem identification & motivation, define objectives for a solution, and design & development, which collectively underpin the construction of the artifact.
To position this chapter within the overall research process, Figure 4 illustrates how these steps contribute to the development of the Circular Maturity Tool (CMT)'s alpha version. Subsequent demonstration, evaluation, and communication steps leading to the beta version (v2) and final artifact (v3), are addressed in Chapter 4.

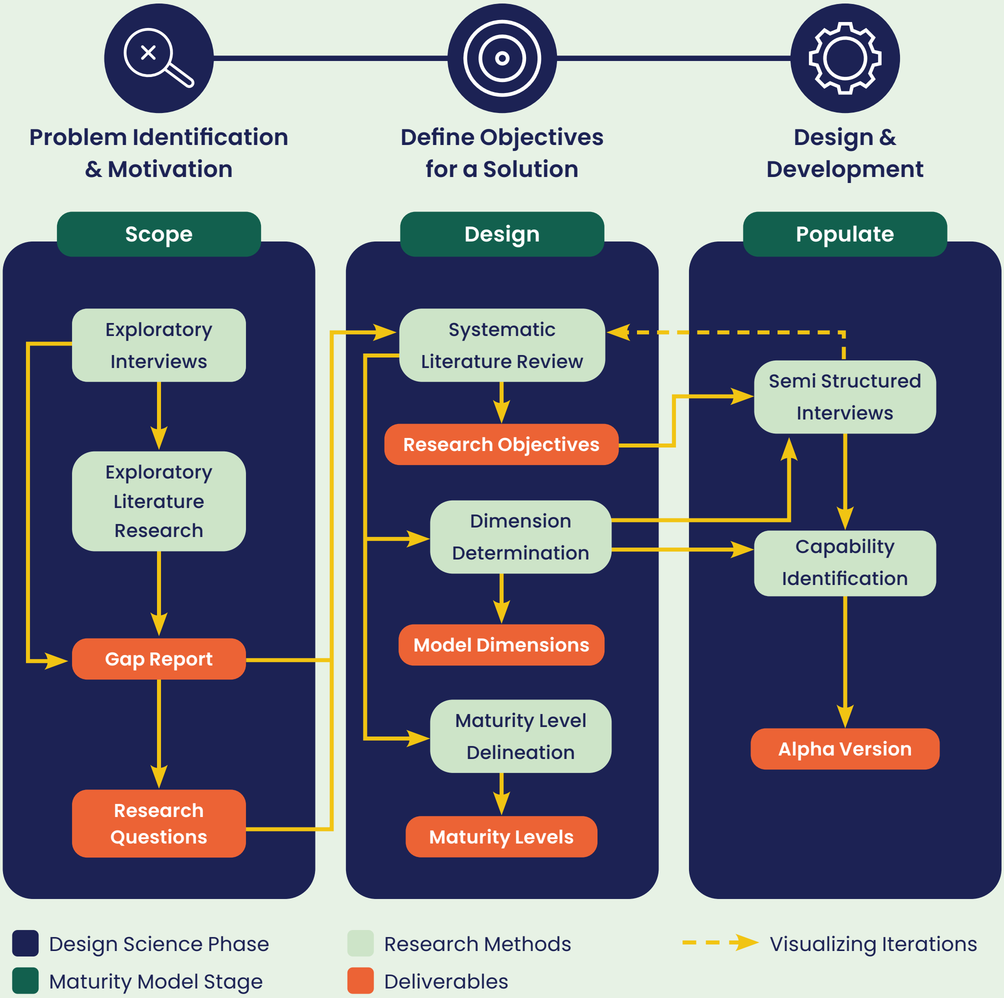
3.2 Methodology

This section elaborates on the methodology for constructing the alpha version of the CMT. The focus is on the initial three steps of the DS process, which collectively shaped the artifact's foundation (see Figure 4).

3.2.1 Step 1: Problem Identification and Motivation

Our first step is about problem identification and motivation. A growing number of firms view Circular Economy (CE) as an opportunity to adopt a novel and improved business strategy (Corbos, et al., 2023), however, the majority struggle with the transition to CE (Cagno et al., 2023).

Figure 4: Building the Alpha Version



Despite numerous potential solutions to increase the effectiveness of the circular transition, it is yet to be determined which solution is the most suitable (Cagno et al., 2023). In order to enhance a firm's efficiency in incorporating CE principles, it is crucial to monitor the improvement in CE Performance by establishing indicators, metrics, and analytical criteria (Kuzma et al., 2021; Linder et al., 2020) at various levels (Baratsas et al., 2022; Geng et al., 2012; Ghisellini et al., 2016; Su et al., 2013). Recent studies have increasingly emphasized evaluating the degree of circularity, leading to the development of Maturity Models (MMs) for CE. However, most of these CE MMs do not take a systemic approach, implying that they examine a firm's individual components separately, not considering the entire firm as a single unit (Julkovski et al., 2023; Kayikci et al., 2022; Sehnem et al., 2020; Uhrenholt et al., 2022).

Moreover, while the literature proposes numerous approaches, methods, and metrics (Elia et al., 2017; Lindgreen et al., 2020; Parchomenko et al., 2019; Saidani et al., 2019), consistency in goals, scope, and potential applications is lacking (Baratsas et al., 2022). Consequently, there are no standardized methods for assessing CE Performance or use of terminology (such as metrics or dimensions) (De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Sassanelli et al., 2019; Vinante et al., 2021). Table 7 presents nine exemplary studies on measuring CE Performance at the firm level.

Table 7: Exemplar Studies Illustrating the Research Gap

	Quantitative	Qualitative	Validated Scale	Micro Level	Number of Indicators	Context	Fundamental Premise
Corbos et al. (2023)	✓	✓	✓	✓	36	Strategic Procurement	Competitiveness
Khan et al. (2020)	✓		✓	✓	63	Firm-level (dynamic capabilities)	Dynamic Capabilities
Kuzma et al. (2021)		✓			149	Not Applicable	Innovation
Mishra et al. (2022)	✓	✓	✓	✓	30	Developing Countries	Barriers
Pigosso and McAloone (2021)		✓		✓	30	Manufacturing	Assessment
Sacco et al. (2021)		✓		✓	45	Circular Value Chain	Assessment
Urain et al. (2022)		✓		✓	165	Industrial Companies (manufacturing, Spain)	CE Integration Industrial Companies
Vinante et al. (2021)		✓		✓	365	Value Chain	Classification Framework
Vranjanac et al. (2023)	✓		✓		7	EU27 Countries	CE Innovation
This Dissertation	✓	✓	✓	✓	67	Manufacturing	CE Performance

Apparently, there is an urgent need for a systemic and validated measurement scale that includes a limited number of indicators to measure CE Performance. Thus, compared to current studies that focus on specific perspectives like dynamic capabilities, innovation, or integration, this research adopts a comprehensive approach.

3.2.2 Step 2: Define Objectives for the Solution

Determining Objectives

The second step focuses on defining the objectives for a solution. Because the research problem originates from the conceptual and methodological shortcomings of extant CE assessment approaches, this research aims to design a circular maturity artifact that provides firms with a comprehensive and standardized tool to systemically evaluate CE Performance at the organizational level.

Systematic Literature Review

To better understand CE Performance, scope our research, and design and populate the maturity dimensions of our CMT, we conducted a systematic literature review (SLR). To ensure a transparent, structured, and replicable approach, we applied the four-stage approach by Denyer and Tranfield (2009): (i) screening, (ii) sampling, (iii) analysis, and (iv) synthesis, often used in the field of CE (Batista et al., 2019; Bressanelli et al., 2019; Vegter et al., 2020).

Screening

This research integrates the scholarly fields of CE and organizational performance evaluation. To retrieve the relevant literature effectively from these fields, we developed a search string at its intersection. Measurement of circularity includes two major constructs, "measure" and "circular". The term "measure" is used inconsistently within the context of CE, reflecting substantial variation in its scope and application. These differences include the level of assessment (product, organizational, or system-wide), the specific focus (environmental, social, or economic aspects), the type of developer (academic researchers, industry practitioners, or policymakers), and their alignment with broader methods outside CE, such as general sustainability assessments (Sacco et al., 2021). It is important to note that other terms are used to describe assess-ment frameworks, such as measures, metrics, index, method, or indices (Saidani et al., 2019; Walzberg et al., 2021). When measuring sustainability and CE at the micro level, the term 'indicators' has previously been widely used (Keeble et al., 2003; Saidani et al., 2019). These terms are often used interchangeably to describe assessment frameworks and methods that aggregate and simplify quantitative or qualitative data for assessment purposes (Kristensen & Mosgaard, 2020; Saidani et al., 2019; Veleva & Ellenbecker, 2001; Walzberg et al., 2021). Most of them extend their scope beyond the traditional indicator as a singular point of concentrated information. To capture the wide range of applied terms, Lindgreen et al. (2020) use the term "assessment approaches". In total 20 keywords are identified to capture the measurement (Table 8).

Table 8: Keywords Related to Measurement

Keyword	Alternatives
perform*	performance, performing, performances, perform
assess*	assessment, assessing, assessments, assess
metric*	metric, metrics
method*	method, methods, methodology
maturit*	maturity, maturation, maturities
measur*	measure, measuring, measurement, measurements
indices	indices
index*	indexing, index
indicato*	indicator, indicators
framew*	framework, frameworks
variab*	variables, variability, variables
paramete*	parameter, parameters
dashboa*	dashboard, dashboarding, dashboards
capabili*	capability, capabilities
dimension*	dimension, dimensions
subdimension*	subdimension, subdimensions
subdimension*	subdimension, subdimensions
level*	level, levels
theme*	theme, themes
segment*	segment, segments

In a similar vein, we use synonyms to capture the circular construct as completely as possible (see Table 9).

Table 9: Keywords Related to Circularity

Keyword	Alternatives
circular*	circular, circularity
"circular* econom*"	CE, circularity economy
"close* loop"	close loop, closed loop
sustain*	sustainability, sustainable

By employing these specified keywords alongside their corresponding alternatives, we constructed a formalized search string suitable for Scopus. The syntax within this search string is: [keyword circular] AND [keyword measure]. The ensuing combined string:

> (circular* OR "circular* econom*" OR "close* loop" OR sustain*) AND (perform* OR assess* OR metric* OR method* OR maturit* OR measur* OR indices OR index* OR indicato* OR framew* OR variab* OR paramete* OR dashboa* OR capabili* OR dimension* OR subdimension* OR subdimension* OR level* OR segment* OR theme*)

To ensure a focused and manageable data set for analysis, we decided to only further evaluate articles retrieved through a search restricted to the *TITLE* field (see Fathifar et al., 2017, for a similar approach). This refinement of focusing on articles that explicitly address the topic in their title aligns with best practices for systematic reviews, as it improves the accuracy and thematic relevance of the results. Gusenbauer and Haddaway (2021) emphasize the importance of precision in systematic review strategies, especially to reduce irrelevant hits and ensure thematic alignment. Similarly, Kitchenham and Charters (2007) argue that narrowing the scope of the search can significantly reduce the workload associated with selecting irrelevant studies. Moreover, Okoli and Schabram (2015) highlight that targeting primary studies with central contributions to a topic, typically those that feature the key concepts in their title, enhances the quality of systematic reviews. By focusing on *TITLE* field results, we aim to avoid including indirectly related articles, often incorporated in search results through abstracts or keywords, as also noted by Sugimoto et al. (2015). This approach ensures that the evaluated literature addresses our research objectives directly, while maintaining methodological rigor and a feasible evaluation process.

Sampling

To enable research selection and evaluation, we compiled a set of inclusion and exclusion criteria, described in Table 10.

Table 10: Inclusion and Exclusion Criteria for Article Selection

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles and peer-reviewed conference proceedings	Non-peer-reviewed articles and conference papers (e.g., preprints, blog posts, white papers)
Written in English	Non-English articles
Year of publication: 2009-2022	Published before 2009 or after 2022
Fully published articles	Articles in press, unpublished manuscripts
-	Book chapters, dissertations, and gray literature

Analysis and Interpretation

The remaining articles were reviewed and evaluated to gain insights on circularity measurement, CE Performance, CE metrics, and CE assessment strategies. Articles focusing primarily on material flow analysis, life cycle analysis, or related methodologies were excluded, aligning with our goal to create an assessment framework that offers a comprehensive perspective. Furthermore, while sustainability and circularity are closely related, our research focuses specifically on circularity measurement rather than broader sustainability concepts. Sustainability was included as a keyword to ensure that relevant CE studies were unintentionally omitted, given that some authors use sustainability as an umbrella term for circularity.

However, articles that primarily discuss sustainability without a clear link to CE principles, such as those focusing solely on corporate social responsibility or generic environmental reporting, were excluded. Subsequently, a backward and forward snowball sampling method was implemented as outlined in Wohlin (2014). The online tool Connected Papers (see Appendix O) identified pertinent literature on the current status of circularity measurement as well as its adoption and implementation in practice. Connected Papers leverages the principles of co-citation and bibliographic coupling to construct a force-directed graph. A set of seminal articles relevant to our research question was selected based on their citation count (i.e., how frequently they have been cited by other works), the references they cite, publication year, and journal. The remaining set is defined as the reference set that we used for further evaluation.

Synthesis of the Findings

The reference set was reviewed to identify foundational principles, dimensions, and maturity levels. Applying additional search strings to the reference set revealed a subset of key studies explicitly addressing key dimensions of circular maturity.
The selection process specifically included search terms related to “dimensions” and their alternatives, ensuring that only studies with an explicit focus on dimensions were considered. These dimensions align with the previously analyzed broader themes: circularity measurement, CE Performance, metrics, and assessment strategies, offering a structured perspective on how firms progress in circular transitions. The refined subset provided the theoretical basis for the CMT.

Determining Dimensions

Then dimensions were determined using four primary perspectives. These perspectives include: (A) CE-maturity from research studies specifically addressing CE Performance, (B) broader dimensions derived from the CE literature, (C) maturity dimensions as applied in the context of Small and Medium Enterprises (SMEs), recognizing that SMEs face unique challenges and resource constraints in implementing CE practices, and

they account for the majority of firms (Dey et al., 2022), and (D) practice-based MMs addressing CE-maturity in applied frameworks and industry tools.
The definitive articulation and validation of these dimensions were achieved iteratively in conjunction with the Step 3 activities.

Maturity Level Delineation
Furthermore, this step facilitated the initial delineation of the maturity levels, with refinements conducted iteratively alongside Step 3.

3.2.3 Step 3: Design and Development

Semi-Structured Interviews
For the design and development phase, we initiated the analysis of the semi-structured interviews by adopting an abductive research approach (Romme & Holmström, 2023). Romme (2003) demonstrates that structured feedback loops and qualitative data enhance the applicability of design artifacts. Furthermore, scholars such as Baldassarre et al. (2020), Romme and Dimov (2021), Romme and Holmström (2023), and Talmar et al. (2020) argue that abductive reasoning supports the refinement of novel ideas, thereby increasing the value of the developed artifact.

Qualitative insights were collected through 54 semi-structured interviews with C-level managers from 37 firms, conducted between 2016 and 2022. All interviewees gave their informed consent. The interviews were conducted using a predefined interview guide covering firms' circular ambitions, current practices, organizational challenges, and perceived capability needs. An overview of the interviews is included in the online Appendices (see Appendix L #15). Practitioner feedback provides iterative refinement, ensuring alignment with organizational realities (Holmström et al., 2009; Simon, 1996). To ensure a diverse and representative sample, firms based in the Netherlands were selected based on their engagement with CE practices, sectoral diversity, and geographical distribution within the country. The sample included firms from manufacturing, retail, and service industries. This national context aligns with the Dutch government's aim to achieve a fully CE by 2050, as outlined in the National CE Programme 2023–2030 (Ministerie van Infrastructuur en Waterstaat, 2023), and is further supported by findings from the Circularity Gap Report, which positions the Netherlands as a global frontrunner with a circularity rate of 24.5% (Circle Economy, 2020b). At each firm, interviewees were purposively selected based on their strategic and/or operational involvement in circular transition activities, to ensure participants were sufficiently informed about both current practices and organizational decision-making.

All interviews were recorded and transcribed, resulting in 705 pages of transcripts. These were analyzed using Atlas.ti (version 24.2.1, built 32295, see Appendix O). We adopted a two-pronged coding strategy. First, deductive coding was performed using category codes derived from the SLR. Second, inductive sub-coding was applied to answer the open question: "What influences CE Performance?" Text segments were identified and sub-codes developed using the interviewees' terminology wherever possible (Magnani & Gioia, 2023).

A total of 2,872 text segments were coded, resulting in 393 distinct sub-codes across 20 category codes (for an overview of the inteeviews and the code list, see the online Appendices, Appendix L #04 and #15). To ensure analytic trustworthiness and inter-coder reliability, three researchers independently coded a subset of transcripts (achieving an average of 52% similarity). Their results were aligned in joint review sessions. Discrepancies in coding were resolved through scholarly deliberation, including revisiting original transcripts and consulting the broader dataset. This collaborative and iterative approach ensured consistent and rigorous thematic analyses, culminating in an average similarity of 95% thereafter.

Capability Identification

Capability identification creates items for each dimension by identifying capabilities in existing models and developing additional capabilities. Utilizing the deductive method for capability creation as referenced by Lee et al. (2015), Schwab (1980), and Tojib et al. (2008), the CMT dimensions were employed to derive capability-based scale items that operationalize each dimension. To ensure reliability and internal consistency, multiple capabilities were generated for each dimension (Allen & Yen, 2001; Lee et al., 2015; Moore & Benbasat, 1991; Nunnally, 1978). When suitable, existing scale items that had undergone empirical testing were reviewed and modified for the newly created measure (Chang, 2001).

3.3 Findings

This section presents the outcomes of the first three steps in the DS cycle, detailing how the artifact was developed and refined through iterative engagement with the literature and empirical data.

3.3.1 Step 1: Problem Identification and Motivation

To validate and contextualize the problems identified in the literature, we conducted preliminary exploratory activities aimed at understanding how firms currently assess their CE Performance and where the main challenges lie. These included qualitative interviews with 13 C-level managers and sustainability managers across diverse industries, as well as a review of firm-level documents and reporting practices (see Table 34, in Appendix D).

The insights confirm that, while firms express a strategic commitment to CE principles, they often lack a systemic assessment framework or practical tool to evaluate their circular maturity. Existing assessments are ad hoc, department-specific (e.g., focused on procurement or product reuse), or aligned with external reporting standards rather than internal strategy development. Key challenges identified by the participants included: insufficient internal coherence among departments regarding circular goals, challenges in translating circularity concepts into quantifiable initiatives and actions, and ambiguous selection of indicators and interpretation of performance metrics. These findings confirm the assertion in the literature (see Chapter 1.2) that most existing CE MMs are either too abstract or narrowly scoped. Furthermore, practitioners expressed the need for an industry-agnostic, transparent, and user-friendly tool that could guide both assessment and strategic improvement. This step thus confirms the relevance and urgency of developing an artifact that fills this empirical and methodological gap.

3.3.2 Step 2: Define Objectives for the Solution

***Figure 5:** Systematic Literature Review (adapted from Denyer and Tranfield, 2009)*

Systematic Literature Review

Figure 5 summarizes the SLR process. In the context of screening, the search query identified 1,514,241 documents in the *TITLE-ABS-KEY* category, with 53,970 including our keywords exclusively in the *TITLE*. By utilizing the inclusion and exclusion criteria outlined in Table 10, the number of *TITLE* documents was narrowed down from 53,970 to 10,424.

By leveraging the evaluation criteria focused on *analyzing and interpreting*, we narrowed down our selection from 10,424 articles to 684, ensuring that the research aligned with the intended focus. Using both back- and forward snowballing techniques, Connected Papers assisted in identifying additional articles, detailed in Table 11.

It became apparent that saturation occurred after reviewing six foundational articles, leaving a total of 759 articles in the reference set. Of these, a subset of 21 studies focus on dimensions relevant to CE. The selected studies are listed in Tables 12 and 13, divided into perspectives A and B, as discussed in the next section.

Table 11: Connected Papers Additions

Reference	Articles new	Articles total
Scopus search result		684
Sacco et al. (2021)	27	711
Saidani et al. (2019)	21	732
Kristensen and Mosgaard (2020)	9	741
Franco et al. (2021)	14	755
de Oliveira et al. (2021)	4	759
Lindgreen et al. (2020)	0	759

Table 12: Circular Maturity Dimensions (Perspective A)

Reference	Articles new
Kayikci et al. (2022)	Economic, Environmental, Social, Policy, Process, Product, Strategy, Technology
Uhrenholt et al. (2022)	Value Creation, Governance, People & Skills, Supply Chain & Partnership, Operations & Technology, Product & Material
Pigosso and McAloone (2021)	Organization, Strategy & Business Model Innovation, Product & Service Innovation, Manufacturing & Value Chain, Technology & Data, Use, Support & Maintenance, Take-back & End-of-Life Strategies, Policy & Market

Determining Dimensions

The full-text review of the articles listed in Tables 12 and 13 reveals that a smaller subset directly discusses circular maturity (Perspective A). Notable studies by Kayikci et al. (2022), Pigosso and McAloone (2021), and Uhrenholt et al. (2022) explore MMs within the CE domain, but differ in their approach to dimension inclusion. For instance, while Uhrenholt et al. (2022) limit findings to primary dimensions and maturity levels, Kayikci et al. (2022) incorporate subdimensions and Pigosso and McAloone (2021) extend the model with aspects applicable for practical implementation.

Analyses of other relevant studies, included in Perspective B, reveal additional recurring dimensions across CE studies. Specifically, five major observations emerge from these studies: (i) the inclusion of the Triple Bottom Line (TBL) approach (social, economic, environmental), as noted in studies by Kristensen and Mosgaard (2020), Kuzma et al. (2021), and Walker et al. (2021); (ii) integration of core CE principles, as developed by Potting et al. (2017) and extended to include business model innovation by Baratsas et al. (2022) and Rossi et al. (2020); (iii) recognition of spatial levels (micro, meso, macro), reflecting CE's connection across levels, highlighted by De Pascale et al. (2021) and Kirchherr et al. (2017); (iv) specific dimensions such as supply chain management and technology, which require further examination in CE contexts, as suggested by Martinho (2021) and Jain et al. (2018); and (v) some studies emphasize detailed capability dimensions, which can function as subdimensions, as per Joshi et al. (2020).

Table 13: CE Reference Set Dimensions (Perspective B)

Reference	Dimension
Baratsas et al. (2022)	Spatial levels: micro, meso, macro; 3R principles: reduce, reuse, recycle; TBL dimensions
Dev et al., 2020	Performance dimensions that need to be addressed in the context of operational excellence to improve sustainable supply chain including flexibility, collaboration, transparency, innovation, and relational capabilities of the supply chain (SC). Two key dimensions: i) The degree to which a firm improves the circularity of its products and processes by leveraging its resources; ii) The degree to which a firm introduces promotions around the CE through marketing
De Pascale et al. (2021)	Three double classification: first according to the three spatial dimensions of sustainability, macro, micro and meso, then on the basis of the 3R Core CE principles and three SD classification
Di Maio and Rem (2015)	Dimensions are used in a different context
Garza-Reyes et al. (2019)	Recycling, Reuse, Remanufacturing Material substitution, & Other resource efficiency practices
Jain et al. (2018)	SCM dimensions: integration of green supply chain aspects, business model, SCM, product design
Joshi et al. (2020)	Network Design (D1), Product design and visibility (D2), Traceability and Transparency (D3), Co-creation (D4), Destination Attractive-ness (D5), Adoption of Climate Change (D6), Governance (D7), Market Linkage (D8), Local Community Contribution, Sustainable Livelihoods (D9), Food Security (D10) and Self-Efficacy (D11)
Kirchherr et al. (2017)	Core principles (4R framework, waste hierarchy, systems perspective); Enablers: Business models, Consumers
Kravchenko et al. (2019)	Sustainability dimensions, business processes, CE strategies
Kravchenko et al. (2020)	TBL perspective
Kristensen and Mosgaard (2020)	Recycling, Disassembly, Lifetime, Efficiency, and Reuse
Kuzma et al. (2021)	Sustainability dimensions. Results indicate the lack of integration of the social dimension and predominance of environmental indicators, lack of indicators for the meso level, and concentration of metrics for the product level. Apart from using the sustainability dimensions (Social, Environmental and Economy), 10 categories for indicator categorization are introduced

Table 13: CE Reference Set Dimensions (Perspective B) – Continued

Reference	Dimension
Lindgreen et al. (2020)	18 of the 74 approaches analyzed include all three dimensions of sustainable development, and also a circular dimension. Roughly one quarter has a design approach. Suggested key desired properties of CE assessment approaches include making use of existing assessment methodologies such as Life Cycle Assessment (LCA), and a closer collaboration between science and practitioners to consider end-user needs in the CE assessment approaches.
Martinho (2021)	Environmental, social, economic, technical
Merli et al., 2018	9 structural dimensions + analytical categories
Potting et al. (2017)	Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover
Rossi et al. (2020)	Seven dimensions: material, energy, waste, 3Rs, water, emissions, and general CE indicators
Walker et al. (2021)	TBL dimensions

Because the maturity of SMEs is another pertinent research topic in the context of CE, and our aim is to develop an assessment framework with a systemic view (Perspective C), we conducted an additional Scopus literature search on "maturity" and SMEs. This search yielded several relevant studies that inform the determination of dimensions. Table 14 highlights the representative dimensions in MMs dedicated to SMEs.

Table 14: SME Maturity Dimensions (Perspective C)

Reference	Dimension
Mittal, Romero, and Wuest (2018)	Finance, People, Strategy, Process, Product
Williams et al. (2019)	Strategy, Products/Services, Technology, People & Culture, Management & Processes
Paavel et al. (2017)	Strategy & Policy, Management & Control, Organization & Processes, People & Culture, Information Technology

The dimensions identified in these studies show substantial overlap with the CE studies from perspectives A & B.

Finally, Perspective D draws from practice-based sources. The Ellen MacArthur Foundation's Circulytics tool, for instance, provides a comprehensive assessment framework with 12 dimensions and 60 indicators, focusing on areas like Innovation, Strategy & Planning, and Water & Energy (Ellen MacArthur Foundation, 2022).

In the Netherlands, Route Circulair offers a circular maturity roadmap encompassing 11 dimensions, targeting circular transition through Leadership, Stakeholder Engagement, and Financing (Ewen et al., 2017).

The terminology employed across perspectives reflects ongoing conceptual evolution (Sacco et al., 2021). Despite variations in formulations, the dimensions exhibit consistent meaning and content. Inconsistencies suggest conceptual immaturity within the field, a challenge frequently cited in the literature (Nobre & Tavares, 2021; Uhrenholt et al., 2022). Consequently, expanding the literature scope would unlikely yield novel insights into CE dimensions. Table 15 lists the references, perspectives (A-D), and number of dimensions used to assess (CE) maturity. This Table can also be viewed via the Excel file uploaded in Appendix L #08.

Table 15: Dimension Bibliography

#	Reference	Circular Matuity (A)	Reference Set Dimensions (B)	SME Maturity (C)	Circular Maturity Practice Based (D)	# of Dimensions
1	Baratsas et al. (2022)		✓			9
2	Ellen MacArthur Foundation (2022)				✓	12
3	De Pascale et al. (2021)		✓			9
4	Dev et al. (2020)		✓			7
5	Di Maio and Rem (2015)		✓			0
6	Potting et al. (2017)		✓			10
7	Garza-Reyes et al. (2019)		✓			12
8	Jain et al. (2018)		✓			2
9	Joshi et al. (2020)		✓			11
10	Kayikci et al. (2022)	✓				8
11	Kirchherr et al. (2017)		✓			15
12	Kravchenko et al. (2019)		✓			5
13	Kravchenko et al. (2020)		✓			3
14	Kristensen and Mosgaard (2020)		✓			3
15	Kuzma et al. (2021)		✓			3
16	Lindgreen et al. (2020)		✓			3

Table 15: Dimension Bibliography – Continued

#	Reference	Circular Matuity (A)	Reference Set Dimensions (B)	SME Maturity (C)	Circular Maturity Practice Based (D)	# of Dimensions
17	Martinho (2021)		✓			4
18	Merli et al. (2018)		✓			9
19	Mittal, Khan, et al. (2018)			✓		9
20	Paavel et al. (2017)			✓		5
21	Pigosso and McAloone (2021)	✓				8
22	Rossi et al. (2020)		✓			9
23	Ewen et al. (2017)				✓	11
24	Simetinger and Basl (2022)			✓		5
25	Uhrenholt et al. (2022)	✓				6
26	Walker et al. (2021)		✓			3
27	Williams et al. (2019)			✓		6

In line with the definitions of the identified dimensions, these were systematically organized into overarching dimensions and subdimensions, culminating in a total of 59 dimensions (refer to Table 35 / Appendix E, or the Excel file in the online Appendix L #08. Further elaboration on the classification and identification of dimensions and sub-dimensions is presented in Tables 16 (Other Dimensions), 17 (CE Strategy Dimensions), 18 (CE Social Dimensions), 19 (CE Economic Dimensions, and 20 (CE Environmental Dimensions). We discuss each Table in more detail.

Table 16: Other Dimensions

Nr.	Level 1 Classification	Dimension	Frequency
38	general	Other	1
39	general	Sustainable development	1
40	general	General CE dimensions	1
41	general	General	2
42	not applicable	Food security	1

Table 16: Other Dimensions – Continued

Nr.	Level 1 Classification	Dimension	Frequency
57	spatial	Macro	3
58	spatial	Meso	3
59	spatial	Micro	3

General

Referring to Table 16, we took the following steps to determine the applicable dimensions:

- Eliminate "not applicable" [42].
- "General" is the collection of general firm and/or business unit information for benchmarking/cross-case analysis at a later stage. Thus, "General" is not a dimension of measuring CE Performance. We merged the four inputs [38], [39], [40], and [41] into one "General" category [41] and removed dimensions [38], [39], and [40].
- As our focus is the organizational level, we did not need the spatial dimensions [57], [58], and [59]) and therefore removed them.

General items in Economic [31], Environmental [37], and Social [56] could be removed because they are used as a level 1 classification. After the above procedure, the following dimensions remained: 6 in CE Strategy (see Table 17), 26 in Economic (see Table 19), 7 in Environmental (see Table 20), and 12 in Social (see Table 18). Strategy, Social, Economic, and Environmental are classified as main dimensions.

Table 17: CE Strategy Dimensions

Nr.	Dimension	Frequency
1	CE strategies	1
2	Recover	1
3	Reduce	4
4	Reuse	4
5	Recycle	4
6	Takeback & End-of-life Strategies	1

CE strategy

The dimension CE strategy now covered six indicators ([1], [2], [3], [4], [5], and [6]). However, in line with Potting et al. (2017), the scope of this dimension was extended to the 9R CE strategies. Furthermore, these CE strategies were not considered as (sub) dimensions but as capabilities. Summarizing: CE strategies were reduced to one dimension [1]. The other indicators ([2], [3], [4], [5], and [6]) were moved to capabilities and deleted from this list.

Table 18: CE Social Dimensions

Nr.	Dimension	Frequency
45	Internal Culture	1
46	Local Community Contribution / Sustainable livelihoods	1
47	Self Efficacy	1
48	Social equity	1
49	Future generations	1
50	People	2
51	Leadership	2
52	Customers	2
53	Policy & Market	3
54	People, Skills & Culture	6
55	Governance	7
56	Social	10

Social

Numbers [45], [46], [47], [48], and [49] all have a frequency of 1. Internal Culture [45] (Ewen et al., 2017) refers to a firm's culture. This is equivalent to "culture" as part of item [54] (People, Skills, Culture), mentioned by 6 (Ellen MacArthur Foundation, 2022; Mittal, Khan, et al., 2018; Paavel et al., 2017; Simetinger & Basl, 2022; Uhrenholt et al., 2022; Williams et al., 2019). Items [48] (Social Equity) and [49] (Future Generations) are mentioned by Kirchherr et al. (2017). However, those two dimensions are goals rather than dimensions summarizing capabilities (Kirchherr et al., 2017). No. [46] (Local community contribution) and [47] (Self-efficacy) are mentioned by Joshi et al. (2020), studying CE dimensions in the Agritourism Cluster. Self-efficacy was initially coined, but at a later stage dropped by expert judgment (Joshi et al., 2020). Joshi et al. (2020) identified Local Community Contribution and Sustainable Livelihoods as the second most crucial dimension. This finding suggests that local community involvement can aid the development of agritourism supply chains. Denying its relevance for agri-culture, a more general interpretation of dimensions is "Supply Chain & Partnership" [26]. Similar to [45] (Internal Culture), [50] (People) is also part of [54] (People, Skills & Culture). Within the overarching Social dimension, this leaves the following 8 keywords: "People, skills, culture, leadership, governance, policy, market, and customers." Generally, policy pertains to precise regulations and directives that oversee a firm's behavior. Governance, on the other hand, pertains to the wider structure that steers the firm's management and orientation.

According to Kayikci et al. (2022), policy is connected to various subdimensions such as corporate sustainability policy, employees, governance, incentives, organizational culture, and regulations. Pigosso and McAloone (2021) define policy and market as legislative frameworks and markets' external preparedness for the advancement and delivery of circular solutions (Pigosso & McAloone, 2021).

Table 19: CE Economic Dimensions

Nr.	Dimension	Frequency
7	Business Models	1
8	Stakeholder management	1
9	Value Creation	1
10	Services	1
11	Manufacturing & Value Chain	1
12	Technical	1
13	Use, Support & Maintenance	1
14	Destination Attractiveness	1
16	SCOR Dimensions	1
17	Economic Prosperity	1
18	Marcom & Sales	2
19	Innovation	2
20	Financing	2
21	Network Design	2
22	Product Design & Visibility	2
23	Traceability & Transparancy	2
24	Co-creation	2
25	Operations	3
26	Supply Chain & Partnership	4
27	Processes	5
28	Technology	8
29	Strategy	9
30	Products & Services	9
31	Economic	10
43	Plant, Property, and Equipment Asset	1
44	Facilities / Internal Business Operations	1

Economic

The overarching "economic" dimension accounts for 26 items, with technology, strategy, and products & services mentioned respectively 8, 9, and 9 times. Only 12 items are mentioned once. Business Models [7] is only mentioned by (Kirchherr et al., 2017). In the shift towards CE, innovative business models have been identified as a facilitator (Brennan et al., 2015; Ellen MacArthur Foundation, 2013). The foundation of CE lies in Circular Business Models (CBMs) (Lewandowski, 2016). According to Kirchherr et al. (2017), there is a perception that practitioners place greater emphasis on the practical aspects of CBMs than academics (Kirchherr et al., 2017). With the private sec-tor driving the transition to CE, not paying attention to business models is like driving without a driver at the steering wheel (Kirchherr et al., 2017). In summary, the presence of business models that support CE strategies comes under strategy [29]. Also, looking at CE-supporting business models includes value creation [9] (Uhrenholt et al., 2022). Furthermore, stakeholder management [8] is only mentioned by Ewen et al. (2017) and is nested under strategy [29]. Value creation is discussed by Uhrenholt et al. (2022). They characterize value creation as the methodologies employed for producing and capturing value from CE initiatives, such as sales models, take-back programs, and services that extend the life cycle of products. This also encompasses environmentally beneficial outcomes like resource and emissions conservation and regeneration. Thus, the act of creating value involves implementing business models that facilitate CE practices. Pigosso and McAloone (2021) introduce the concept of Manufacturing & Value Chain, emphasizing its significance as a strategic area for enhancement. This involves forging new partnerships to facilitate circular solutions and pinpointing possibilities for industrial symbiosis. In contrast to Pigosso and McAloone (2021), this aspect shares many similarities with the Supply Chain & Partnership dimension as discussed in another source [26]. Technical [12] as a dimension is only mentioned by Martinho (2021), referring to the properties of materials, components, and products (Iacovidou et al., 2017). Nine technical metrics are identified for Resource Recovery from Waste (RRfW) management assessment methods: reusability, remanufacturability, mass recyclability, technical recyclability, mass recoverability, energy recoverability, lower heating value, technical recoverability of components and products, and technical advancement. These metrics are related to [30] products & services. The metrics can be taken into account when looking at capabilities. The dimension Use, Support & Maintenance [13] is mentioned by Pigosso and McAloone (2021) as *"the capabilities needed to provide enhanced maintenance and repair services, to create more value from the solutions provided"*. The three questions they ask refer to take-back systems, disassembling and remanufacturing products, and recovering value from end-of-life products (Pigosso & McAloone, 2021). In general, these dimensions refer to [7] business models and [30] products and services.

Dimension Services [10] (mentioned in 1) is also mentioned in [30] (products & Services). Therefore, [10] overlaps with [30]. The dimension Destination Attractiveness [14] is mentioned by Joshi et al. (2020). Similar to the discussion of [46] and [47] under social, the attractiveness of the destination specifically focuses on the agri-tourism sector (Joshi et al., 2020). In a broader context, this is related to Supply Chain & Partnership [26]. SCOR [16] as a dimension is mentioned by Jain et al. (2018) and is part of [26] Supply Chain & Partnership. The dimension Economic Prosperity [17] mentioned by Kirchherr et al. (2017) is the main CE objective, followed by environmental quality. Together with environmental quality and social equity, economic prosperity is part of the three aims to be achieved simultaneously in sustainable development (Taylor, 2016). As such, economic prosperity is equal to [31] economic which is this overarching dimension. The dimension Marcom & Sales mentioned by Dev et al. (2020) and Ewen et al. (2017) also features in numerous interviews. This dimension will be kept as a subdimension. Innovation [19] as a dimension is used by Circulytics (Ellen MacArthur Foundation, 2022) and mentioned by Dev et al. (2020). Circulytics poses one question: "*To what extent is (are) your innovation function(s) geared toward designing products/services/business models in line with CE principles?"* (Ellen MacArthur Foundation, 2022). This question can be linked to [27] Processes, asking about the innovation process with regard to CE. Nevertheless, innovation in the realm of operational excellence to enhance the sustainable supply chain is introduced by Dev et al. (2020), drawing from work by Mangla et al. (2020). This encompasses aspects such as adaptability [21], cooperation [22], openness [23], and interpersonal skills [26]. As such, innovation is part of [27] processes and [26] Supply Chain and Partnership. The financing dimension [20] is used by Circulytics (Ellen MacArthur Foundation, 2022) and is mentioned in many interviews. Strangely enough, there was no mention of deductive analysis. Network design [21], was mentioned by Joshi et al. (2020) and Dev et al., 2020 (flexibility as a dimension of a CE-empowered supply chain). This item is part of [26]. Product design & Visibility [22] was mentioned by Dev et al. (2020) as collaboration and as a dimension of the supply chain by Joshi et al. (2020). The same applies to Network Design, part of [26] and also to Traceability & transparency [23] (the same as [22] and [21]). Joshi et al. (2020) define co-creation [24], design, and development of the product/ services as a dimension of the various partners involved in the supply chain (Jonkman et al., 2019). Thus, reference [24] is a component of the capabilities introduced in [26]. According to Dev et al. (2020), co-creation is described as *"the extent to which a company enhances the circularity of its products and procedures by utilizing its resources."* Ultimately, the utilization of resources related to products and processes can be seen as a dimension of the process [27].

The dimension Operations [25] is mentioned by Circulytics (Ellen MacArthur Foundation, 2022), and also by Mittal, Khan, et al. (2018) and Uhrenholt et al. (2022), who combine Operations with Technology and propose the following definition: *"The equipment and systems in place for performing CE activities (e.g., machinery and tools, systems aiding the scheduling and identification of appropriate treatment according to value potential)."* Mittal, Khan, et al. (2018) propose Operations as a dimension in smart manufacturing and the Industry 4.0 MM. A definition in this regard is lacking. Some exemplary capabilities are decentralization of processes, modeling, simulation, and interdisciplinary or inter-departmental collaboration (Mittal, Khan, et al., 2018). Finally, Circulytics formulates the following questions on the theme Operations: *"To what extent are suitable Information Technology (IT) and digital systems in place to support a circular business model, products, or services? To what extent are processes established to support circular business models, products, or services? To what extent are suitable plant, property, and equipment assets in place to support CBMs, products or services?"* (Ellen MacArthur Foundation, 2022). From this, we see that Operations [25] mainly discusses Process [27], Technology [28], and Plant, Property and Equipment (PPE) [43]. The dimension Supply Chain & Partnership [26] is mentioned during interviews in a different context and appears in several studies. This dimension is kept as a subdimension. The dimension Processes [27] has 5 mentions in the literature and features in interviews. Furthermore, Kayikci et al. (2022), Kravchenko et al. (2019), and Paavel et al. (2017) and Williams et al. (2019) talk about processes with subdimensions: *"Life Cycle Assessment for Circularity, Circular Value & Co-Creation Processes, Reverse Operations, Circular Phases of the End-of-Life Cycle, Circular Manufacturing Systems, Closed-Loop Supply Chains."* Williams et al. (2019) retrieve the process dimension from a mixed-method approach. A precise definition is lacking, which complicates establishing a direct connection to CE. Kravchenko et al. (2019) describe business processes as "a series of organized tasks that a firm undertakes to accomplish a particular goal." They categorize these as primary processes, associated with day-to-day operations (such as manufacturing and logistics), and secondary processes, linked to managerial functions (like strategic management and governance) (Kravchenko et al., 2019). Technology [28], strategy [29], and products & services [30] are considered as dimensions. Dimension Assets, Plant, Property and Equipment (PPE) [43] is only used by Circulytics (Ellen MacArthur Foundation, 2022). They used this item within the Operational theme [25], but also as a separate theme. For the specific theme, the focus is quantitative; the first one uses the Likert scale. For our research, PPE is part of the Process and Operations dimension category. Finally, the dimension Facilities / Internal Business Operations [44] is mentioned in Ewen et al. (2017) and occurs in several interviews. This dimension is considered as a subdimension.

Table 20: CE Environmental Dimensions

Nr.	Dimension	Frequency
15	Address Climate Change	1
32	Emissions	1
33	Environmental quality	1
34	Waste hierarchy	2
35	Water	2
36	Energy	2
37	Environmental	12

Environmental

The overarching dimension Environmental [37] is discussed in 12 (46%) of the 26 publications. Water [35], energy [36], and waste hierarchy are mentioned twice, while the others (Addressing Climate Change [15], Emissions [32] and Environmental Quality [33]) are only mentioned once. Environmental Quality [33] is discussed by Kirch-herr et al. (2017), and together with Economic Prosperity [17] and Social Equity [48], these are the ultimate goals of Sustainable Development [39]. This means that [33] is linked to [37]. Waste hierarchy [34] is mentioned by Kirchherr et al. (2017) and Rossi et al. (2020). Kirchherr et al. (2017) connect waste hierarchy to the varieties of the R framework, as proposed by Potting et al. (2017) and Sihvonen and Ritola (2015) and Van Buren et al. (2016). Rossi et al. (2020) apply Waste as a general term for all that is no longer of use. In conclusion, waste hierarchy is expressed with the CE strategy [1] and related R-Strategies [2], [3], [4], and [5]. The concept Climate Change Adoption [15] is referenced by Joshi et al. (2020), yet it lacks a clear explanation. Embracing climate change involves acknowledging the associated potential threats and advantages and formulating strategies to mitigate risks and leverage opportunities. This is crucial because climate change poses a significant global challenge that impacts all sectors of society. By incorporating climate change considerations in their activities, firms can reduce their greenhouse gas emissions, minimize their vulnerability to climate-related risks, and enhance their reputation as ethical and sustainable entities. Emissions [32] are discussed by Rossi et al. (2020), whereas Water [35] and Energy [36] are addressed by Rossi et al. (2020) and Circulytics (Ellen MacArthur Foundation, 2022).

In conclusion, Table 21 delineates the ultimate CMT, comprising four primary dimensions and eight subdimensions, which collectively form a comprehensive set of 10 dimensions for evaluating circular maturity. Narratives for each dimension, derived from the literature, are incorporated in Table 22.

Table 21: Retrieved Dimensions and Subdimensions

Dimension	Subdimension
Strategy	
People	Communication
People	Skills
People	Leadership & Culture
Operations	Products & Services
Operations	Innovation & Technology
Operations	Value Chain Cooperation
Operations	Financing
Operations	Internal Operations
Environmental	

Maturity Level Delineation

Drawing upon available assets, firms may advance through successive maturity levels in CE Performance, with each stage denoting a specific level of capability and commitment to circular practices. Based on the literature, we distinguish the following maturity levels:

None: At this initial level, there is minimal awareness of CE principles and actions are limited to meeting legal requirements, such as waste disposal regulations. Circularity is not integrated in strategic goals, and there are no proactive efforts towards circular practices (Bilal et al., 2020).

1. **Basic:** Firms are recognizing the need for circular practices and may implement isolated, low-impact initiatives, such as simple waste reduction or recycling efforts. CE remains peripheral to the core strategy and processes, and most activities are ad hoc (De Pascale et al., 2021; Garza-Reyes et al., 2019).
2. **Explorative:** At this stage, firms pilot circular projects across different functions, often to test the potential benefits and feasibility of circular strategies. The focus is on learning and experimentation, with a few dedicated resources and minor investments in circular activities. Collaboration with external partners may be limited to single project engagements (Joshi et al., 2020; Kuzma et al., 2021).
3. **Systematic:** Circular principles become embedded in a firm's operations and strategic processes. Firms implement circular initiatives systematically, incorporating them in daily operations and long-term plans. Formal training, partnerships, and structured collaborations support circular efforts, with regular evaluations and performance metrics (Kristensen & Mosgaard, 2020; Lindgreen et al., 2020).

4. **Integrative:** At this advanced level, circular practices are holistically embedded in the firm's overarching strategy and seamlessly integrated across the entire value chain. Firms engage actively with suppliers, customers, and other stakeholders to co-create circular value, fostering a resilient and adaptive ecosystem. Circular principles inform decision-making across departments, while processes and technologies are optimized to enable closed-loop flows. Performance is systematically monitored through comprehensive circularity metrics, allowing firms to identify synergies, minimize externalities, and align business models with long-term sustainability goals (De Pascale et al., 2021; Garza-Reyes et al., 2019; Merli et al., 2018).
5. **Regenerative:** At this highest maturity level, firms transcend circular optimization to actively restore, renew, and regenerate natural and social systems. These firms aim to create net-positive impacts, enhancing biodiversity, replenishing ecosystems, and contributing to societal well-being. Circularity is no longer a strategic alignment but a foundational purpose, guided by principles such as regenerative design, nature-based innovation, and the pursuit of value within planetary boundaries. Advanced technologies support distributed, restorative models, while organizational culture embodies circular values across all functions. Regenerative firms often act as pioneers, influencing industry standards and shaping policy agendas (Gaziulusoy & Brezet, 2015; Raworth, 2017; Schaltegger et al., 2012).

These stages represent a progression from basic awareness and adherence to CE principles towards a thorough and strategic integration, aligning closely with models of organizational transition aimed at sustainable development (Geels, 2011; Loorbach, 2017; Schaltegger et al., 2012).

Table 22: Descriptive Narratives of Key Dimensions Related to CE Performance

Dimension	Narratives
Strategy	Strategy involves defining a sustainable, circular vision integrated in core business policies, emphasizing partnerships, certification adherence, and innovative approaches to align business objectives with CE principles. This strategic approach allows firms to align with CE values while pursuing long-term market positioning (Bilal et al., 2020; de Arroyabe et al., 2021; Merli et al., 2018)
Finance	Finance in a CE context involves allocating resources to circular initiatives while prioritizing economic feasibility and sustainability. This approach aligns financial incentives with long-term environmental and economic gains, such as by reinvesting profits into circular projects and minimizing waste-related costs (Di Maio & Rem, 2015; Kuzma et al., 2021; Paavel et al., 2017; Williams et al., 2019)

Table 22: Descriptive Narratives of Key Dimensions Related to CE Performance – Continued

Dimension	Narratives
Products & Services	Developing products and services with circularity in mind involves designing for longevity, reuse, and recyclability. The focus is on life-cycle management and minimizing waste generation through innovations that facilitate sustainable consumption (Garza-Reyes et al., 2019; Lindgreen et al., 2020; Moultrie et al., 2007)
Innovation & Technology	This dimension emphasizes using digital tools (e.g., Internet of Things (IoT), data analytics) and innovative design to support circular operations, such as extending product life and optimizing material reuse (Dev et al., 2020; Martinho, 2021; Simetinger & Basl, 2022)
Environmental	Environmental commitment entails actions that reduce negative environmental impacts, such as emissions and resource depletion, while aligning practices with CE standards, thus enhancing eco-efficiency (Bilal et al., 2020; Joshi et al., 2020; Kravchenko et al., 2020)
Value Chain Collaboration	Value chain Collaboration centers on establishing partnerships that support circular strategies, optimize resource sharing, and promote collective engagement in sustainable practices (Lindgreen et al., 2020; Merli et al., 2018; Moultrie et al., 2007)
Leadership & Culture	This dimension involves embedding CE values in corporate culture through leadership that actively promotes sustainability, shaping an organizational mindset supportive of circular practices (Garza-Reyes et al., 2019; Kristensen & Mosgaard, 2020; Williams et al., 2019)
Skills	Skills development focuses on equipping employees with knowledge in sustainable design, resource-efficient processes, and circular supply chain management, critical for supporting a circular transition (Joshi et al., 2020; Moultrie et al., 2007; Simetinger & Basl, 2022)
Communication	Communication in circular contexts emphasizes transparency and stakeholder engagement, ensuring the sharing of circular goals and progress to enhance awareness and foster commitment to sustainability (Bilal et al., 2020; Merli et al., 2018)
Internal Operations	This involves embedding circular principles directly within operational workflows, emphasizing waste reduction and resource efficiency to create a sustainable internal ecosystem (Dev et al., 2020; Garza-Reyes et al., 2019; Lindgreen et al., 2020)

Maturity Levels per Dimension from Literature

Based on the above, each dimension can be linked to every maturity level, illustrating how firms evolve as they advance in embracing circular practices (See Table 23).

Table 23: Maturity Levels per Dimension

Dimension	None	Basic	Explorative	
Strategy	No strategic focus on circularity; compliance driven practices dominate. (Bilal et al., 2020)	CE considered sporadically, often as add-ons to compliance activities. (Garza-Reyes et al., 2019)	CE strategies piloted but lack cohesive alignment with broader organizational goals. (Kuzma et al., 2021)	
Finance	Budgets focus on traditional fossile energy based models with no consideration of circularity. (Bilal et al., 2020)	Limited allocation to low-cost circular projects, often focused on recycling. (Van Buren et al., 2016)	Pilot CE initiatives supported by flexible funding with informal ROI measures. (Van Buren et al., 2016)	
Products & Services	Product life-cycles follow a traditional fossile energy based model; no circular design considerations. (Bilal et al., 2020)	Incremental improvements in resource efficiency through minor design modifications. (Bocken et al., 2016)	CE pilots test product designs for durability and recyclability. (Moultrie et al., 2007)	
Innovation & Technology	Technology vestments minimal focus only efficiency provements. (Bilal et 2020)	Basic technology supports resource reduction and waste management. (Kuzma et al., 2021)	Digital tools like IoT and resource tracking systems are piloted. (Simetinger & Basl, 2022)	
Value Chain Collaboration	Partnerships focus on traditional supply chains; no circular collaboration exists. (Bilal et al., 2020)	Occasional resource recovery collaborations occur, often opportunistic. (Witjes & Lozano, 2016)	CE-focused pilots with supply chain partners test circularity potential. (Witjes & Lozano, 2016)	
Leadership & Culture	Leadership focuses solely on compliance or efficiency; CE is absent. (Bilal et al., 2020)	Awareness of CE increases but with minimal engagement from leadership. (Merli et al., 2018)	Some leaders champion circularity, supported by grassroots employee initiatives. (Kuzma et al., 2021)	

	Systematic	Integrative	Regenerative
	CE principles are integrated into organizational strategy with defined objectives. (Kristensen & Mosgaard, 2020)	CE strategy evolves through continuous feedback loops, driving core operations. (Martinho, 2021)	CE strategy incorporates ecosystem regeneration and global resource decoupling goals. (Korhonen et al., 2018)
	Dedicated CE budgets and systematic ROI tracking formalized. (Lindgreen et al., 2020)	CE embedded into financial planning, influencing long-term investments. (Martinho, 2021)	Financial systems prioritize high-impact regenerative and sustainable projects. (Kristensen & Mosgaard, 2020)
	Products designed for repairability, reusability, and closed-loop re-cycling. (de Arroyabe et al., 2021)	CE principles guide all product and service offerings, promoting lifecycle optimization. (Kristensen & Mosgaard, 2020)	Fully circular and regenerative products use biodegradable or fully renewable materials. (Bocken et al., 2016)
	Automation and advanced tools like AI optimize circular processes. (Dev et al., 2020)	Blockchain andmachine learning ensure transparency and systemic circularity. (Joshi et al., 2020)	Technologies actively regenerate ecosystems and enhance circular innovation. (Van Buren et al., 2016)
	Circular practices systematically embedded into value chain operations. (Garza-Reyes et al., 2019)	Sustained partnerships maximize circular value across networks. (Jain et al., 2018)	Regenerative ecosystems emphasize systemic resource recovery and restoration. (Jain et al., 2018)
	CE principles are championed by leadership, with formal training and initiatives. (Garza-Reyes et al., 2019)	CE fully embedded in culture, with leadership recognition of sustainability achievements. (Garza-Reyes et al., 2019)	Leaders foster regeneration-focused innovation as a cultural cornerstone. (Williams et al., 2019)

Table 23: Maturity Levels per Dimension – Continued

Dimension	None	Basic	Explorative	
Skills	No CE-specific skills exist; traditional capabilities dominate. (Bilal et al., 2020)	Employees self-learn basic CE concepts, often informally. (Moultrie et al., 2007)	Training programs introduce CE concepts, targeting key roles. (Moultrie et al., 2007)	
Communication	No CE-related communication internally or externally. (Bilal et al., 2020)	CE occasionally mentioned in reports or updates; lacks focus. (Merli et al., 2018)	CE efforts shared with select stakeholders to build initial engagement. (Kravchenko et al., 2020)	
Internal Operations	Operations optimized purely for cost efficiency and productivity. (Bilal et al., 2020)	Small waste reduction practices introduced but lack scalability. (Merli et al., 2018)	Pilots target disassembly, material recovery, and reuse. (Bilal et al., 2020)	
Environmental	Environmental efforts focus on compliance with legal requirements. (Bilal et al., 2020)	Basic environmental improvements aim at cost savings and minor impact. (Merli et al., 2018)	Pilot projects focus on reducing emissions and improving biodiversity outcomes. (Simetinger & Basl, 2022)	

	Systematic	Integrative	Regenerative
	Comprehensive skill development supports organizational CE goals. (Kristensen & Mosgaard, 2020)	CE knowledge is key to workforce development, fostering circular innovation. (Van Buren et al., 2016)	Advanced capabilities enable regenerative design and ecosystem-level practices. (Martinho, 2021)
	Structured communication strategy emphasizes CE achievements across channels. (Martinho, 2021)	CE branding drives customer engagement and promotes organizational transparency. (Kristensen & Mosgaard, 2020)	Transparent messaging highlights regenerative and ecosystem-focused goals. (Kristensen & Mosgaard, 2020)
	CE principles formalized across operations; waste processessystematized. (Kristensen & Mosgaard, 2020)	Operations maximize resource reuse and contribute to circular ecosystems. (Merli et al., 2018)	Fully regenerative operations achieve zero waste and create net-positive impacts. (Dev et al., 2020)
	CE principles deliver measurable environmental performance improvements. (Dev et al., 2020)	Regenerative practices restore ecosystems and reduce environmental footprints. (Kristensen & Mosgaard, 2020)	Activities are ecosystem-centered, restoring biodiversity and ensuring long-term sustainability. (Korhonen et al., 2018)

This therefore serves as a comprehensive assessment framework for understanding the pathways firms may follow as they integrate circular principles in their strategies and operations to achieve higher circular maturity levels. Firms may benchmark themselves to assess their current status and identify areas for growth. More strategic dimensions such as Leadership & Culture, progress from basic awareness to a stage where circularity becomes a core organizational value. Similarly, more operational dimensions such as Value Chain Collaboration evolve from ad hoc occasional collaboration to collaborating in regeneration across networks.

3.3.3 Step 3: Design and Development

Interview Analysis

The analysis of the 54 interviews provided empirical grounding for the CMT's conceptual design, i.e., the alpha version. The interviews uncovered real-world challenges that firms encounter when implementing CE initiatives and validated the relevance and structure of the proposed maturity dimensions. Practitioner feedback was instrumental in iteratively refining the artifact. The interviews revealed common concerns, including misalignment between departments, difficulties in operationalizing CE goals, and the lack of standard performance metrics. These findings reinforced the conceptual categories derived from the literature and informed additional dimensions relevant to organizational practice.

Table 24: Quotes on Dimensions and Maturity Levels

Dimension	None	Basic	Explorative	
Strategy	"Circularity isn't a focus for us, compliance takes priority." *(X002, RC090)*	"We're starting to consider circular principles." *(X006, RM028)*	"Pilots help us align strategy with circularity." *(X003, RM030)*	
Finance	"Traditional budgeting methods don't include CE." *(X002, RM089)*	"Some resources are allocated to circular initiatives." *(X009, RC010)*	"We've started budgeting for circular pilots." *(X011, RM011)*	
Products & Services	"Our products are designed for traditional markets." *(X004, RC005)*	"We've started exploring circular design ideas." *(X006, RM028)*	"Product lifecycles are extended through better design." (X011, RC085)	

To deepen the understanding of how each dimension influences CE Performance, we developed descriptive narratives for each maturity dimension. These narratives integrate interview insights and are supported by the SLR. Within each narrative, three components were addressed comprehensively: (i) an elucidation of the maturity dimension, providing a detailed understanding of its scope and implications; (ii) comprehensive insights and recurrent motifs extracted meticulously from the interview data; and (iii) exemplary practitioner perspectives incorporated to enhance contextual comprehension and offer real-world applicability. The narratives can be found in Table 22.

Maturity Levels per Dimension from Interviews

To ensure that the CMT captures real-world perspectives, Table 24 extends the maturity framework by incorporating qualitative insights from interviews. Each cell represents a specific maturity level for a dimension, enriched with direct quotes from interviewees. By embedding these voices in the CMT, a practical validation takes place and the gap between theoretical constructs and practical realities becomes smaller.

	Systematic	Integrative	Regenerative
	"Our strategy integrates CE with measurable targets." (X015, RC045)	"CE goals drive our innovation and operations." *(X018, RC020)*	"We focus on regeneration and long-term circular strategy." *(X023, RC083)*
	"Dedicated funds support scaling circular solutions." (X019, RC021)	"Circularity is central to financial planning." *(X022, RM024)*	"Investments aim for maximum sustainability impact." *(X024, RM025)*
	"Repairability and recyclability are now priorities in design." *(X014, RM014)*	"Circularity is central in all new product designs." *(X020, RM022)*	"Our products are fully biodegradable and regenerative." *(X024, RM026)*

Table 24: Quotes on Dimensions and Maturity Levels – Continued

Dimension	None	Basic	Explorative	
Innovation & Technology	"We focus on efficiency, not circular technology." *(X007, RC007)*	"Tech helps with basic waste tracking." *(X008, RC008)*	"IoT is used to monitor circularity in products." *(X015, RC045)*	
Value Chain Collaboration	"We don't engage in circular partnerships." *(X002, RM089)*	"Occasional collaboration for recycling exists." *(X006, RM028)*	"Supply chain partners support pilot CE projects." *(X011, RC085)*	
Leadership & Culture	"Circularity isn't a leadership priority." *(X002, RC090)*	"Some leaders are beginning to support CE initiatives." *(X006, RM028)*	"Leadership promotes CE through awareness programs." *(X011, RC085)*	
Skills	"We don't have CE specific expertise." "Operations are designed to regenerate materials and energy." *(X025, RM026)* *(X002, RM089)*	"Employees develop recycling skills on their own." *(X008, RC008)*	"Training programs are available for CE skills." *(X011, RM011)*	
Communication	"Circularity isn't communicated internally or externally." *(X005, RC006)*	"Circularity is mentioned in some internal updates." *(X008, RC008)*	"Successes in CE projects are shared internally." *(X012, RM012)*	
Internal Operations	"Operations prioritize cost savings over sustaina-bility." *(X002, RM089)*	"Small steps toward waste reduction are underway." *(X008, RC008)*	"Circularity pilots focus on material reuse and recovery." *(X011, RC085)*	
Environmental	"We only meet regulatory environmental standards." *(X002, RM089)*	"Basic efforts reduce environmental costs." *(X006, RM028)*	"Pilot initiatives target reduced emissions and better water use." *(X012, RM012)*	

	Systematic	Integrative	Regenerative
	"Digital twins and AI optimize CE processes." *(X019, RC021)*	"Blockchain enhances transparency across circular systems." *(X022, RM024)*	"Our tech enables ecosystem-wide regeneration." *(X023, RC083)*
	"We collaborate deeply with our supply chain for CE." *(X018, RC020)*	"Strong partnerships maximize circularity along the value chain." *(X022, RM024)*	"We collaborate to regenerate resources across networks." *(X025, RM026)*
	"CE goals are part of our leadership's strategic focus." *(X019, RC021)*	"Leaders champion CE and embed it in culture." *(X022, RM024)*	"Sustainability leadership drives innovation and regeneration." *(X024, RM026)*
	"Structured development programs support circularity." *(X018, RC020)*	"We hire and train specifically for CE expertise." *(X021, RC023)*	"CE skills are advanced and foster systemic regeneration." *(X024, RM026)*
	"CE is part of both internal and external communications." (X019, RC021)	"Circularity drives our branding and external messaging." *(X022, RM024)*	"Our communication emphasizes regeneration and shared impact." *(X025, RM026)*
	"All processes now integrate CE principles." (X018, RC020)	"Operational systems maximize resource efficiency and reuse." *(X022, RM024)*	"Operations are designed to regenerate materials and energy." *(X025, RM026)*
	"Environmental metrics are embedded in CE processes." *(X019, RC021)*	"Our focus is on ecosystem protection and restoration." *(X022, RM024)*	"We actively regenerate ecosystems through our operations." *(X024, RM026)*

Including interview data in the CMT underscores the practical challenges and opportunities firms face in embracing circular practices. For example, the interview quotes highlight the importance of leadership support at early maturity levels and the role of collaborative ecosystems at advanced levels of maturity. Moreover, these real-world insights emphasize the iterative nature of circular transitions, where firms navigate diverse hurdles while building capabilities. Finally, the findings demonstrate that achieving higher levels of maturity involves not just technical advances but also cultural changes and sustained commitment.

Capability Identification
After defining the CMT dimensions and maturity levels, the final step was to identify the corresponding capabilities for each dimension. This process began with the reference set from the SLR and was supplemented with coded data from interviews and additional sources identified through backward and forward snowballing.

We created and expanded an initial list of capability items by incorporating relevant existing scale items from the literature (Jun et al., 2006; Rudd et al., 2018; Winterich et al., 2019), resulting in a total of 107 items.

Together, dimensions, maturity levels, and capabilities constitute the CMT alpha version (v1). The next chapter describes the alpha test, when the items were revised and systematically organized to ensure content validity and eliminate ambiguity or redundancy.

3.4 Discussion and Conclusions

The first three phases of the DS methodology laid the conceptual foundation for developing a meaningful and actionable CMT for firms. These phases served not only to contextualize the research within the broader transition challenges of circularity, but also to translate those systemic concerns into actionable firm-level insights. Together, they provide the scaffolding for the CMT that is both scientifically grounded and contextually appropriate for diverse organizational settings.

The literature review and problem framing confirmed that while numerous CE MMs exist, they often lack conceptual coherence, empirical validation, or alignment with managerial needs (Kristensen & Mosgaard, 2020; Lindgreen et al., 2020; Merli et al., 2018; Pigosso & McAloone, 2021). It also exposed the fragmented nature of current approaches to CE Performance measurement, an issue this research explicitly addresses by striving for standardization and systemic applicability.

The objectives defined in the second phase were therefore not merely operational, but also epistemologically motivated to advance both theory and practice.

Stakeholder engagement activities during these early phases, including expert interviews, SLR, and conceptual synthesis, provided a crucial empirical and theoretical grounding. These interactions revealed a widespread desire among firms for clarity, structure, and comparability in navigating the circular transition. In particular, practitioners emphasized the need for diagnostic tools that not only assess maturity, but also stimulate organizational learning and cross-functional dialogue. Moreover, they reinforced the need for a model that accounts for the multi-dimensional nature of CE, one that transcends mere material flows to include cultural, strategic, and systemic factors.

The design requirements established in the third phase formed the artifact's architectural logic. They reflect a deliberate balancing act between comprehensiveness and usability: ensuring the CMT would be sufficiently detailed to capture circular complexity, yet not so cumbersome as to inhibit its adoption by firms. These requirements also introduced the key design tensions that would guide subsequent development decisions, such as the trade-off between generalizability and contextual specificity.

Phases 1 to 3 highlight the dual role of DS in this research: as a methodological guide and as a philosophical stance. By combining theoretical insight, empirical input, and iterative reflection, these foundational steps prepared the ground for the subsequent artifact demonstration, evaluation, and communication phases. The next chapter operationalizes these insights into the testing of the alpha version (v1) and the creation and testing of the CMT beta version (v2), detailing how the artifact was constructed, populated, and underwent validation.

CHAPTER

4

Beta Version Building and Evaluation

4. Beta Version Building and Evaluation

Note: Except for the Introduction and first paragraph of the Methodology, the content of this chapter is part of a manuscript currently under review for publication in Technovation (Wierikx, Raassens, et al., 2026).

4.1 Introduction

This chapter builds on Chapter 3 and continues the integrated Design Science (DS) study by presenting the alpha version evaluation, beta version development and evaluation, and further refinement of the artifact. While Chapter 3 focused on the conceptual foundation and development of the alpha version (v1), this chapter moves into the empirical phase of Circular Maturity Tool (CMT) refinement and validation, resulting in successive iterations of the artifact (v2 and v3).

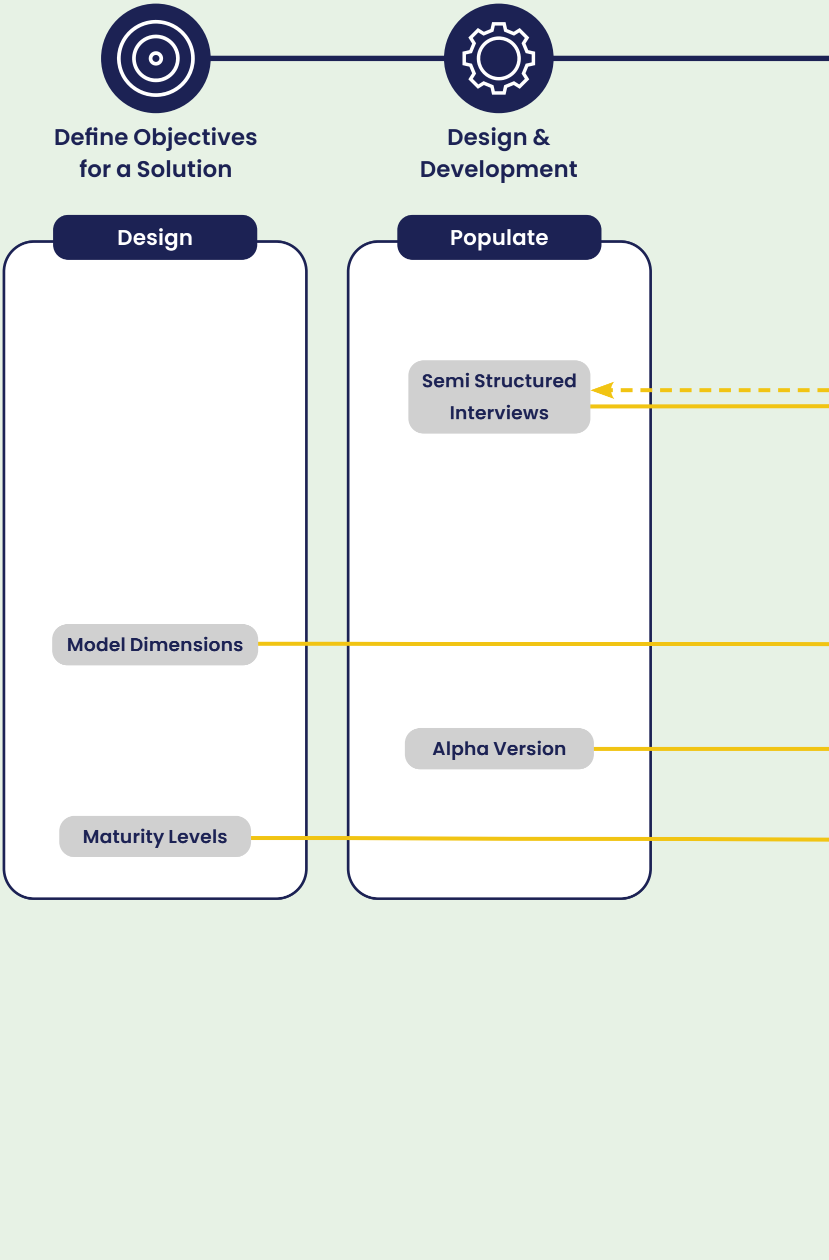
Specifically, this chapter presents the empirical evaluation of the CMT. The evaluation focuses on the CMT's applicability, usability, and validity across diverse organizational and sectoral contexts. This phase corresponds to steps 4 through 6 of the DS process (see Table 4), which constitute the beta phase of CMT development. It emphasizes iterative validation using both quantitative and qualitative methods, in line with the Design Science Validity Framework (DSVF) (Larsen et al., 2025).

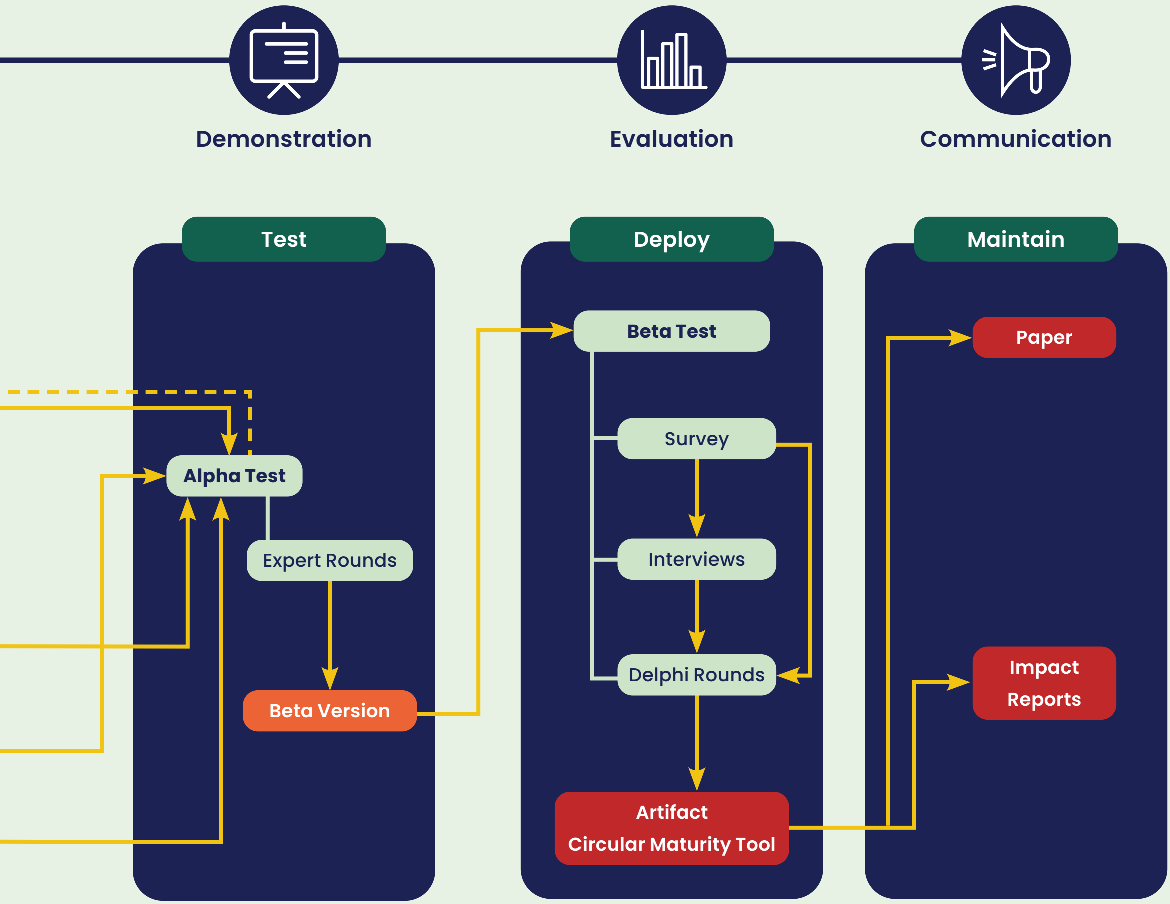
Two core objectives guide the empirical evaluation presented in this chapter. First, it aims to statistically assess the internal consistency, construct reliability, and dimensional validity of the CMT using structured survey data from 145 Dutch firms. This involves examining correlations between maturity dimensions and CE Performance, operationalized through the R-strategies framework (Potting et al., 2017). Second, the chapter incorporates qualitative insights from 36 semi-structured interviews and three rounds of Delphi consultation with experts from academia, industry, and consultancy. These methods serve to contextualize the CMT, refine its content, and ensure its applicability in different organizational settings (Delbecq et al., 1975; Linstone & Turoff, 2002).

To position this chapter within the broader research process, Figure 6 presents the demonstration, evaluation, and communication phases of the DS cycle.

Figure 6:

Overview of the Beta Phase Steps: Demonstration, Evaluation, and Communication




Demonstration
Evaluation
Communication
Test
Alpha Test
Expert Rounds
Beta Version
Deploy
Beta Test
Survey
Interviews
Delphi Rounds
Artifact
Circular Maturity Tool
Maintain
Paper
Impact
Reports

By integrating a multitude of methods, the chapter demonstrates how the CMT evolves from the alpha version (v1), through empirical validation and refinement (v2), into a validated and deployable artifact (v3). This process results in a robust diagnostic tool that enables firms to assess and develop their circular capabilities. At the same time, the chapter illustrates the application of a full-cycle DS approach to sustainability-oriented CMT development (here circular maturity modeling), providing a structured and empirically grounded basis for artifact development within the context of circular maturity modeling(Gregor & Hevner, 2013; Hevner et al., 2004; Romme, 2003). The approach showcased here offers a replicable framework for future sustainability-oriented design research, illustrating how robust artifacts can be developed to tackle complex transitions in business and society.

4.2 Methodology

This section details the methodological execution of the CMT beta phase. The subsequent subsections describe the demonstration, evaluation, and communication steps that structure the empirical testing of the CMT. This approach integrates structured expert feedback, mixed-method data collection, and iterative refinement to validate the tool across diverse organizational settings.

4.2.1 Step 4: Demonstration

The fourth step was the demonstration phase, operationalized as an alpha test, when practitioner panels reviewed and tested the alpha version (v1) of the CMT. The purpose of this phase was to evaluate the CMT's usability, relevance, and practical applicability, and to identify gaps or inconsistencies in the dimensions, maturity levels, and capability items before proceeding to broader validation. The evaluation was guided by predefined criteria, including clarity of items, relevance to Circular Economy (CE) practices, internal consistency across dimensions, and practical applicability in organizational contexts.

The alpha test involved three panels comprising practitioners, researchers, and subject-matter experts from diverse industries. Across three iterative rounds of semi-structured feedback sessions, participants reviewed the ten dimensions, six maturity levels, and 107 capability items of the alpha version (v1) and provided critical insights into their clarity and alignment with organizational practice. This feedback resulted in several refinements. These iterations enhanced the CMT's robustness and clarity, leading to a consolidated structure of four primary dimensions and eight subdimensions, as detailed in Table 21.

The refined CMT was positioned as the beta version (v2), suitable for academic application and practical deployment, and ready for subsequent empirical evaluation (Gregor & Hevner, 2013; Peffers et al., 2007).
A systematic literature review and semi-structured interviews provided the theoretical and empirical foundation for the CMT, while thematic coding and expert validation through alpha testing ensured methodological rigor.

4.2.2 Step 5: Evaluation

For the evaluation phase in DS, corresponding to the deploy stage in Maturity Model (MM) development, a beta test was conducted among firms in the Netherlands. This phase was critical for empirically validating the CMT in real-world organizational settings, ensuring its reliability, applicability, and scalability (Mettler, 2011).

To strengthen the CMT's validity, we applied a multi-method approach: (i) survey-based beta testing using a *structured survey* on the dimensions of the CMT aimed at collecting quantitative data from firms; (ii) semi-structured interviews with survey participants to collect additional qualitative data; and (iii) a Delphi process involving three iterative rounds to refine CMT dimensions and items based on expert feedback. This combination of survey and interview data enabled a mixed-method analysis integrating statistical validation with thematic coding to evaluate the CMT's effectiveness.

To ensure the rigor and validity of the CMT, a Delphi study was conducted, leveraging expert consensus to refine the CMT's dimensions and capabilities. In line with DSVF (Larsen et al., 2025), this process focused on enhancing context validity, ensuring that the CMT remains applicable across different industry contexts. The Delphi rounds iteratively validated the dimensions, ensuring alignment with both theoretical foundations and empirical findings. The Delphi technique, a structured method for facilitating expert panel discussions through iterative rounds, was employed to enhance the reliability of the CMT (Linstone & Turoff, 2002). The panel selection process was designed to incorporate diverse perspectives from academia, consulting, and industry, ensuring a heterogeneous expert group to minimize bias (Delbecq et al., 1975).

The Delphi process unfolded across three structured rounds. Round One focused on an initial assessment of the CMT dimensions, where experts were asked to retain, modify, or eliminate CMT components. Round Two introduced the refined CMT, including definitions of maturity levels, and sought expert validation of proposed changes through structured feedback. Round Three served as a confirmatory phase, finalizing descriptions and maturity definitions to establish consensus (Gallego & Bueno, 2014).

A threshold of 80% agreement determined consensus for CMT components, ensuring robustness in decision-making. To assess the internal consistency of expert evaluations, we employed Cronbach's Alpha, with a satisfactory reliability coefficient exceeding 0.7 (Bland & Altman, 1997). The detailed Delphi process, including expert selection criteria, panel composition, and questionnaire structure, is provided in Appendix I.

4.2.3 Step 6: Communication

The communication phase, focusing on disseminating research findings both during and after the research endeavor, is a central component of DS (Baldassarre et al., 2020). Throughout the research phase, academic scholars, industry practitioners, and policy-makers deliberated on the tool. Following the research phase, dissemination was embodied by articles and by prospective projects aimed at advancing further exploration of the tool (for a project overview, see Appendix N).

4.3 Findings

4.3.1 Step 4: Demonstration

Alpha Testing of the CMT

Alpha testing is a critical step in DS evaluation, allowing researchers to iteratively refine an artifact before broader application (Hevner et al., 2004; Peffers et al., 2007; Vaishnavi & Kuechler, 2015). This phase involved expert-driven validation through three revision rounds, where academics, PhD scholars, and industry professionals engaged in a systematic review of the 107 initial items in the CMT. The goal was to authenticate the CMT's content, enhance clarity, and ensure its applicability within real-world organizational settings.

Validation Process and Refinement

Following DS principles, the validation process adhered to rigorous iterative refinement, a hallmark of constructive research methods (Gregor & Hevner, 2013; Hevner, 2007). Through three expert review cycles, items were screened, modified, and restructured to ensure their relevance to CE practices, precision in defining circular capability levels, and representativeness across diverse organizational contexts, while also eliminating redundancy and ambiguity. After these structured revisions, the CMT was consolidated into 76 validated items, mapped across 10 dimensions and 10 outcome variables.

These outcome variables align with the R-Strategies (Potting et al., 2017), a widely accepted framework in CE research.

Theoretical Foundations and Scientific Grounding A key requirement in DS is that artifacts are rigorously grounded in existing knowledge (Gregor & Hevner, 2013; Peffers et al., 2012). The CMT items are based on a strong theoretical foundation, incorporating both existing validated scales and empirical CE assessments:

- 19 items were adapted from previously validated measurement scales, ensuring construct validity (Calik et al., 2017; Jun et al., 2006; Rudd et al., 2018; Winterich et al., 2019).
- 38 items were derived from CE metrics, as identified by Vinante et al. (2021), enhancing the CMT's empirical rigor.
- 16 new items were developed from the interview analyses to address gaps in assessing circular maturity, ensuring comprehensiveness in evaluation.

Refinements Based on Expert Feedback
Expert feedback during alpha testing provided critical insights for improving the CMT and creating the beta version (v2). Experts noted a need for clearer definitions for example in the Leadership & Culture and Environmental dimensions, prompting refinements with actionable descriptions and real-world examples. Moreover, as Small and Medium Enterprises (SMEs) and large corporations differ in circular capability development, guidelines were introduced to enhance adaptability for different firm sizes, ensuring scalability.

These refinements highlight the iterative nature of DS, where artifacts evolve based on structured evaluation and stakeholder feedback (Hevner et al., 2004; Peffers et al., 2007). The finalized set of validated items, part of the CMT beta version (v2), categorized per dimension and outcome variable, is presented in Appendix F, Tables 36 to 46.

4.3.2 Step 5: Evaluation

Survey Creation To further refine and validate the CMT, we conducted a survey to gather data. Aside from several questions seeking consent, the survey contained three sections. The first section utilized a seven-point Likert scale to assess the CMT v2 items listed in Appendix F, where a score of 1 denoted strong disagreement and a score of 7 denoted strong agreement. This aligns with the CMT's validated scales, which also employ a seven-point scale (Calik et al., 2017; Jun et al., 2006; Rudd et al., 2018; Winterich et al., 2019). Research suggests that a seven-point scale likely offers superior reliability compared to scales with other numbers of options (de Bruin et al., 2005; Oaster, 1989; Preston & Colman, 2000; Tarka, 2017; Wakita et al., 2012).

If a participant was unable to answer the question, an additional answer option in each part of the questionnaire indicated 'Don't know / NA'. Following the approach described by Dawes (2002), the rescaling of a 7-point Likert scale to 6 maturity levels was performed using the following transformation:

where:

$$M_d = \frac{(L_d \cdot M_{max}) - (M_{max} - M_{min}),}{L_{max} - L_{min}}$$

M_d:	Dimensional maturity level d,
L_d:	Likert scale score corresponding to dimension d,
M_{max}, M_{min}:	Maximum and minimum maturity levels,
L_{max}, L_{min}:	Maximum and minimum Likert scale levels.

The survey then asked the respondents to evaluate 10 statements concerning the R-Ladder's performance, as outlined in Table 46 (Appendix F). The guiding question for these ten statements was: *'For each of the following statements, please specify the degree to which your organization has accomplished the following.'* The final part of the survey focused on gathering general information about the firm and the participant.

Beta Test

Survey Data

The survey was accessible to participants from May 2023 through March 2024 and was disseminated via social network platforms and targeted email communications. As indicated in Andrews et al. (2003), the integration of emails with online surveys constitutes a legitimate method to solicit individuals' participation in surveys.
The survey specifically targeted general managers, who were actively solicited through invitations and reminders. The promotional materials explicitly indicated the compensatory benefits associated with participation. Firms involved were promised the provision of a personalized firm report reflecting their performance score, complemented by a comprehensive enumeration of recommendations and prohibitions pertaining to their existing CE Performance. Upon completion of the survey, participants were requested to furnish their email addresses should they wish to receive the study results. It was hypothesized that providing a reward positively influenced participant enrollment. The survey was conducted in close co-operation with the province of Utrecht (see Table 58 in Appendix N).

During the specified timeframe, a total of 145 usable cases were gathered. Inclusion criteria mandated that only cases with fully completed surveys, including the R-Strategy statements, were selected. Appendix G presents the descriptive and correlation characteristics of the dataset, showing predominantly positive and statistically significant relationships between circular maturity items and CE Performance indicators across multiple dimensions, based on Spearman's rank correlation analysis. The online appendices (see Appendix L #14) include a cleaned version of the data set.

Interview Data

To complement the survey, we conducted 36 additional interviews (total length: 27.5 hours, 677 pages of transcript) with survey participants. The interviews followed a semi-structured interview guide focusing on interpreting survey outcomes, validating dimension scores, and identifying contextual factors influencing CE Performance. Within these semi-structured interviews, the scores derived from the survey were deliberated. Furthermore, supplementary data on CE Performance was acquired along with other pertinent information critical for the transition to CE. Appendix H presents the extensions to the respective narratives based on the outcomes of the interview analysis and data comparison. An overview of the interviews is available through the online Appendices (see Appendix L #15).

Refinement with Delphi Analysis

After the three Delphi rounds, the refinements were classified as: (i) changes in dimensions, (ii) additions and deletions in items, and (iii) changes in wording of items.

Refining Dimensions

The dimension *Environmental* was renamed *Environmental Impact Data*. This was to enhance specificity, clarity, and alignment with contemporary sustainability assessment methodologies. The original term was too broad, potentially encompassing general environmental policies and corporate sustainability initiatives rather than focusing on measurable environmental performance. By incorporating impact data, the revised name explicitly emphasizes the use of quantifiable indicators such as carbon footprint, resource consumption, pollution levels, and waste management metrics, ensuring a data-driven approach to circularity evaluation. This change aligns with CE principles that prioritize empirical evidence over qualitative descriptions. Additionally, the updated terminology improves interpretability for both respondents and analysts, reduces ambiguity and reinforces the dimension's role in tracking and improving environmental performance. From a scientific perspective, this adjustment enhances construct clarity within MM assessments, while from a practical standpoint, it ensures that firms can systematically evaluate and improve their circular impact using robust, data-driven metrics.

Renaming the dimension *Finance* to *Business Model* reflects a necessary shift to a more comprehensive and strategic perspective on financial sustainability and value creation. The original term *Finance* was too narrow, primarily implying financial management, investment, and cost control, whereas the broader concept of *Business Model* encompasses the entire value creation logic through which a firm generates, delivers, and captures value. This change aligns with contemporary sustainability and CE paradigms, where financial viability is deeply intertwined with strategic positioning, innovation, and value chain collaboration. The updated terminology ensures that the dimension captures critical aspects such as revenue streams, cost structures, customer value propositions, and partnerships that influence financial resilience and long-term sustainability. Furthermore, adopting the term *Business Model* provides greater alignment with DS and MM methodologies, enabling a more systemic evaluation of a firm's capacity to integrate financial sustainability within broader strategic decision-making. Practically, this modification aids respondents in interpreting the dimension beyond mere financial performance, encouraging a focus on sustainable and innovative business strategies that drive competitive advantage in dynamic markets.

In addition, we decided to conceptually merge the dimensions *Strategy* and *Business Model* in the analysis, while keeping them as distinct constructs in the survey, based on their strong empirical correlation and theoretical interdependence. In contemporary management literature, business models are increasingly seen as a means of executing and operationalizing strategy (Teece, 2010; Zott & Amit, 2010). While strategy de-fines a firm's long-term goals and competitive positioning (Porter, 1996), the business model represents the structural configuration through which value is created, delivered, and captured (Osterwalder & Pigneur, 2010). Research suggests that these concepts are closely intertwined, with business model innovation often serving as a key strategic lever (Casadesus-Masanell & Ricart, 2010). However, for survey respondents, distinguishing between strategic intent and business model structure ensures clarity and precision in measurement. By treating them separately in data collection but integrating them in the analysis phase, the research accommodates both theoretical rigor and empirical validity, mitigating multicollinearity while capturing the systemic nature of organizational sustainability and transition.

Refining Items

The survey underwent a structured refinement process based on Delphi rounds, leading to targeted modifications that enhanced clarity, precision, and alignment with CE principles. As addressed above, several dimensions retained most of their original items, while others underwent notable adjustments. Item wording was revised in multiple dimensions to improve specificity and ensure participants could interpret and respond accurately to the statements.

Redundant or ambiguous items were removed, while new items were introduced to address previously overlooked aspects such as feedback loops, collaboration with stakeholders, technological integration, and service-oriented circular initiatives. Additionally, dimensions related to organizational processes, such as *Leadership & Culture, Internal Operations*, and *Value Chain Collaboration*, saw refinements emphasizing actionable strategies to improve CE Performance. The detailed explanation of items that were deleted, changed, and added as part of the beta test (from v2 to v3) can be found in Appendix J.

***Figure 7:** Artifact: Circular Maturity Tool (CMT)*

R-Ladder

R0 Refuse
R1 Rethink
R2 Reduce
R3 Re-use
R4 Repair
R5 Refurbish
R6 Remanufacture
R7 Repurpose

Maturity Levels

0 None
1 Basic
2 Explorative
3 Systematic
4 Integrative
5 Regenerative

Categories

People & Culture
Operations
Strategy & Approach
Value Chain Collaboration

4.3.3 Step 6: Communication

After the beta test, the final artifact (v3) was established. Figure 7 presents the resulting CMT, which operationalizes circular maturity through a structured set of dimensions, associated capabilities, and corresponding maturity levels.

Following its development, the artifact was actively communicated and applied in practice. Its deployment contributed to the publication of the national impact report on circular entrepreneurship in the Netherlands, titled *De Staat van Circulair Ondernemen 2025* (Pape et al., 2025). A second edition, *De Staat van Circulair Ondernemen 2026*, was released in early 2026 and formally presented to Her Majesty Queen Máxima (Smit et al., 2026). This presentation is illustrated in Figure 8.

Figure 8: *Presentation of the Circular Impact Report to Her Majesty Queen Máxima at the Circular Entrepreneurship Convention, 19 March 2026.*

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This dissemination demonstrates the practical relevance and external validity of the artifact, as it is applied and recognized in real-world contexts at a national level. The CMT is publicly accessible online, supporting its broader adoption and use.[1]

1 https://edu.nl/penrw

4.4 Discussion and Conclusions

This chapter addresses the demonstration, evaluation, and communication phases of the DS process to validate and refine the CMT through both an alpha and a beta test. Applying DSVF ensures that the empirical validation process aligns with systematic validation principles. The integration of criterion validity (expert validation), causal validity (statistical analysis), and context validity (real-world beta testing) reinforces the methodological rigor and increases the trustworthiness of the CMT for assessing circular maturity at the firm level.

4.4.1 Theoretical Contribution

Despite the growing relevance of CE in academic and policy discourse, the concept of circular maturity remains underdeveloped and theoretically fragmented. Most existing MMs in the CE domain focus on isolated business functions, without offering a systemic understanding of how circular capabilities develop within firms (Garza-Reyes et al., 2019; Kristensen & Mosgaard, 2020). Furthermore, many models lack contextual adaptability and empirical grounding, often relying on abstract principles or standardized checklists (Lindgreen et al., 2020; Merli et al., 2018). As noted by de Arroyabe et al. (2021), while numerous indicators and assessment tools exist, few provide integrative frameworks that capture the dynamic, interdependent, and sector-sensitive nature of circular transitions. Consequently, scholars have called for robust, theoretically-informed, and action-oriented models that support firms in navigating circular transitions at different levels of maturity (Linder et al., 2020; Lindgreen et al., 2020).

This research addresses these gaps by advancing the CE field through a theoretical conceptualization of circular maturity. In particular, the developed CMT offers a systemic and empirically grounded artifact that delineates 10 interdependent dimensions of circular maturity: *Strategy, Business Model, Products & Services, Innovation & Technology, Value Chain Collaboration, Leadership & Culture, Skills, Communication, Internal Operations, and Environmental Impact Data*. These dimensions are derived from a systematic synthesis of literature and qualitative interview data, capturing the multifaceted and interdependent nature of circular transitions. Unlike extant MMs in a CE context, by framing maturity as a multidimensional construct, the CMT underscores the need for systemic thinking, where organizational, environmental, and systemic factors are considered simultaneously. By adopting a systemic lens and grounding its dimensions in empirical evidence, this research makes two key theoretical contributions.

First, it extends CE theory by operationalizing the concept of circular maturity, transforming a complex, abstract notion into a structured and measurable artifact.

The CMT's hybrid design, combining descriptive assessments with prescriptive guidance, bridges the gap between diagnostic frameworks that identify the current state of maturity, and action-oriented frameworks that suggest pathways for improvement. Notably, this research developed empirically grounded narratives for circular maturity dimensions, which offer a structured approach for operationalizing CE principles at the firm level. By synthesizing insights from literature and interview observations, the CMT bridges abstract sustainability goals with practical organizational contexts. The CMT addresses the challenge of contextualizing CE principles, providing firms with actionable pathways to understand and advance their circular maturity (Kristensen & Mosgaard, 2020; Sacco et al., 2021).

This dual functionality (i.e., descriptive assessment and prescriptive guidance) not only enhances its utility for practitioners, but also offers a replicable methodology for future research on MMs in this or other domains (Becker et al., 2009; Pöppelbuß & Röglinger, 2011).

Furthermore, the CMT highlights the potential importance of contextualizing circular maturity within specific organizational and industrial settings. While many existing MMs adopt a one-size-fits-all approach, the CMT was developed with input from diverse experts and organizations, suggesting a capacity to address sectoral characteristics, regulatory frameworks, and cultural factors. For example, industries with stringent en-vironmental regulations may prioritize compliance-driven strategies, while others focus on market-driven innovations. These observations align with de Arroyabe et al. (2021), who emphasize the role of interorganizational dynamics and innovation in driving sector-specific CE practices. Although this research provides a foundation, future research should explore the application of the CMT in industries with varying CE practices and in regions with diverse regulatory and cultural environments (Merli et al., 2018; Vinante et al., 2021).

Second, this research demonstrates the value of iterative, interdisciplinary method-ologies in advancing CE scholarship, providing a CMT for integrating qualitative and quantitative approaches in sustainability research. Specifically, by applying DS principles, this research developed the CMT iteratively and systematically. Through iterative coding, evaluation, validation, and refinement, the CMT integrates theoretical constructs with empirical insights, demonstrating the utility of DS to construct robust and practically applicable models (Hevner et al., 2004; Mettler & Rohner, 2009). The development of the CMT exemplifies the pivotal role of DS in translating theoretical constructs into actionable frameworks that promote organizational and societal transitions toward sustainability.

More generally, the CMT demonstrates how DS principles can foster innovation by structuring organizational pathways to circular maturity, enabling firms to identify, explore, and exploit new opportunities for Circular Business Models (CBMs) (Romme, 2003). Thus, this research highlights the transformative potential of DS in fostering innovation ecosystems. By addressing complex, interdisciplinary problems like the transition to a CE, DS demonstrates its capacity to create impactful solutions that align with societal priorities. The iterative development and testing of the CMT offer a replicable CMT for DS researchers aiming to address other global challenges, such as digital transformation, energy transitions, and social equity.

4.4.2 Methodological Contribution

Methodologically, this research demonstrates how DS, still underutilized in circular maturity research, can serve as a rigorous yet adaptable methodological framework for the development and validation of structured assessment tools. The research is, to the best of our knowledge, the first in the CE and, more broadly, the innovation management domain, that applied DSVF to ensure the reliability and rigor of the developed artifact, i.e., the CMT (Moultrie et al., 2007; O'Shea et al., 2021; Talmar et al., 2020; Tiitola et al., 2025). By integrating criterion validity through expert validation (alpha test), causal validity through structural statistical tests, and context validity through beta testing in real-world organizational settings, this research strengthens the empirical robustness of circular maturity assessment. Furthermore, by integrating qualitative and quantitative empirical research with DS, and by completing the full design cycle through beta testing, this work serves as an example of DS research in the technology and innovation management domain. The use of iterative cycles, consisting of literature synthesis, conceptual modeling, and dual-stage testing, provides a replicable pathway for other researchers seeking to develop evaluative instruments in sustainability and transition-oriented research. This methodological contribution directly responds to the call by Romme and Holmström (2023) to demonstrate how DS can advance both rigor and relevance in innovation and entrepreneurship, particularly for addressing complex societal challenges through empirically grounded artifacts.

4.4.3 Practical Contribution

Another contribution of this research is the considerable practical value for firms, industry practitioners, and policymakers in promoting the shift toward a CE. The CMT acts as a complete artifact to evaluate existing circular practices and assess their maturity in ten vital dimensions. This assessment pinpoints specific areas that require improvement, helping firms prioritize actions that enhance resource efficiency, drive innovation, and improve stakeholder involvement (Kristensen & Mosgaard, 2020; Vinante et al., 2021).

In addition to its strategic benefits, the CMT enhances organizational and employee awareness of the complexities and interconnected nature of circular transitions. The artifact encourages firms to address often overlooked elements, such as internal culture and value chain collaboration, which are vital for a successful transition to CE. By highlighting aspects such as leadership and communication, the CMT promotes a design-driven approach to circular innovation, in line with the mechanisms discussed by Liedtka (2015). This awareness is shared across the firm, cultivating a collective grasp of circular principles and their significance in daily operations. These ideas are consistent with de Arroyabe et al. (2021), who emphasize the need for employee participation and collaborative in-novation to embed circularity in business practices. This also aligns with Dimov (2011), who emphasizes that recognizing opportunities in complex environments requires tools that balance clarity with adaptability. The CMT serves as such a tool, helping firms to identify actionable pathways within the broader context of circular transitions. By engaging employees at every level, the CMT promotes a systemic view of the CE, enabling firms to address systemic challenges and integrate CE concepts throughout their operations (Geng et al., 2012; Kirchherr et al., 2017).

From an industrial standpoint, the CMT offers potential to support benchmarking and standardization. It provides a comprehensive structure for firms to assess their circular maturity, which could facilitate comparisons across organizations and sectors. This may foster both competition and collaboration, particularly in industries where CE practices are still emerging (Merli et al., 2018). While full-scale industry adoption and policy integration lie beyond the scope of this study, the empirical grounding and design-based methodology of the CMT offer a strong foundation for future efforts aimed at standardizing CE assessment practices.

Together, these contributions demonstrate the potential of DS to bridge the gap between theory and practice in circular transitions, offering a replicable approach for developing impactful and adaptive solutions to complex sustainability challenges.

4.4.4 Limitations and Directions for Future Research

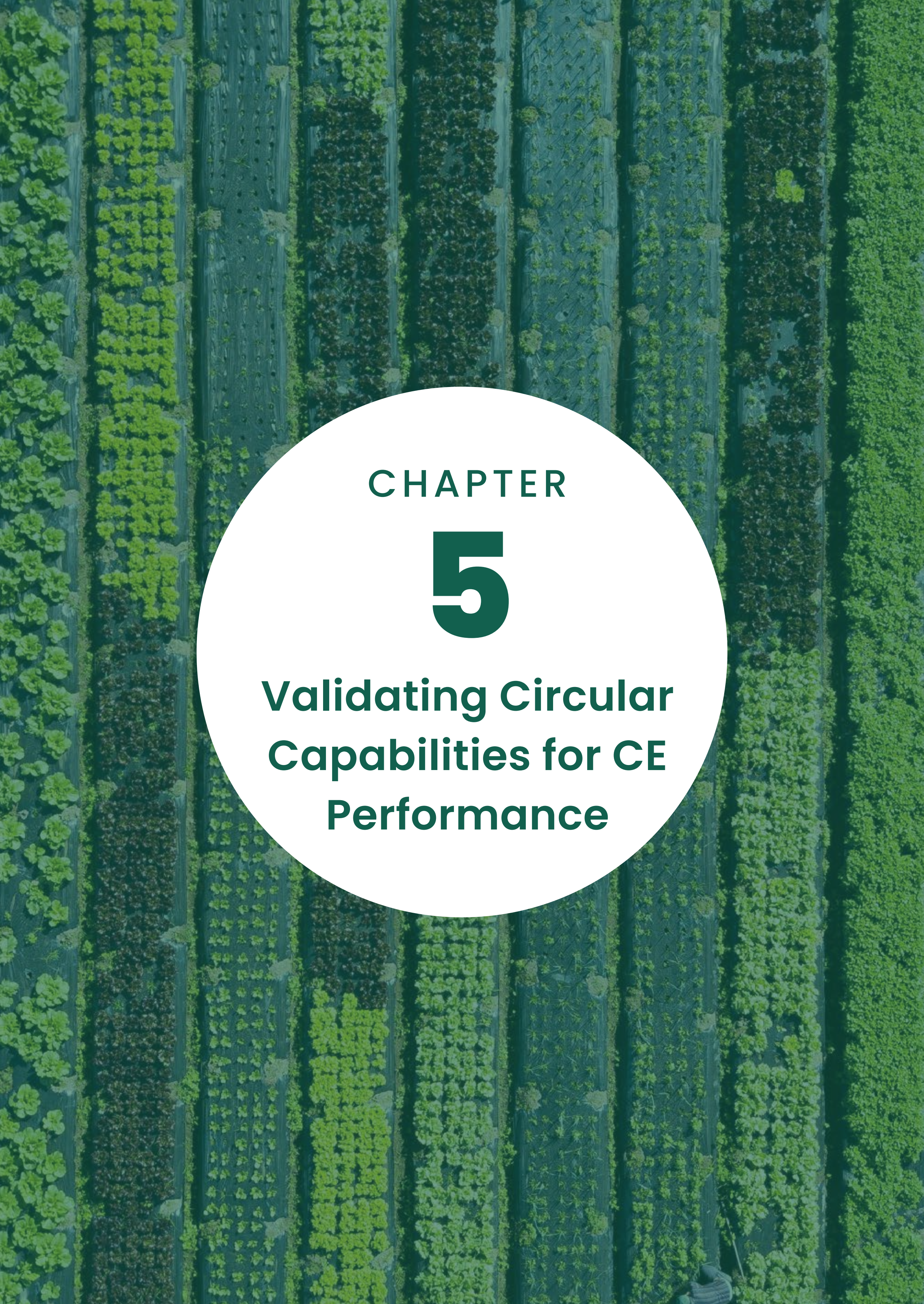
Although this research provides valuable insights on circular maturity, it also has limitations that highlight opportunities for future investigation. First, the developed CMT is static in nature, assessing circular maturity at a single point in time. However, circular transitions are dynamic processes influenced by evolving organizational priorities, market conditions, and technological advancements. Longitudinal studies are essential to capture how firms progress through maturity levels and to understand the drivers and barriers that shape their circular evolution over time. Such research could also explore the temporal relationship between maturity and CE Performance metrics, like resource efficiency and carbon reduction (Geng et al., 2012; Kristensen & Mosgaard, 2020).

Second, while this research focuses on the organizational dimensions of circular maturity, future research should investigate the role of external enablers in accelerating circular transitions. Factors such as regulatory frameworks, industry-wide collaborations, and broader market dynamics play a critical role in shaping circular practices. Examining the interaction between internal organizational factors and external influences could complement the CMT's internal focus, offering an even more systemic view of how firms navigate and adapt to circular transitions. This integration would align with interdisciplinary perspectives on sustainability and system thinking (Kirchherr et al., 2017; Merli et al., 2018). Third, future research could focus on the generalizability of the findings, particularly across different industries, countries, and regulatory frameworks. CE Performance in the services sector, for example, remains underexplored and warrants specific attention. Fourth, future studies could investigate potential interventions or organizational change mechanisms that influence the maturity levels of circular capabilities. Finally, while the empirical validation resulted in a well-structured and evidence-based CMT, the literature indicates that knowledge on CE Performance is still evolving. Investigating mechanisms to incorporate newly emerging insights into the CMT developed in this research represents a promising avenue for future work.

4.4.5 Conclusions

More and more firms are putting the transition to CBMs at the top of their agenda. Although a significant number of solutions is available, many firms are struggling to make the circular transition. The literature reveals that metrics are not consistent and terminology is ambiguous. By deploying a complete DS cycle, including alpha and beta testing with various methods, this research presents an MM for firm transition. This study's conceptual contribution is threefold. First, it advances knowledge on understanding what capabilities a firm requires to become more circularly mature. Second, as one of the first systemic studies, it contributes to making CE Performance measurable through maturity levels. Third, it offers initial empirical evidence suggesting that the ten dimensions of circular capabilities we identified are thematically and structurally aligned with CE Performance, based on within-dimension correlations and expert validation.

This research provides an improved and empirically tested understanding of circular capabilities driving CE Performance. Firms needing to transition to CBMs may resort to the MM identified in this research to inform their decisions. In particular, they could use the outcome of applying the MM to define a transition strategy for improving CE Performance.



CHAPTER

5

Validating Circular Capabilities for CE Performance

5. Validating Circular Capabilities for CE Performance

Note: This chapter complements the Design Science (DS) study presented in Chapters 2–4 by providing a theory-driven empirical validation of the relationships between circular capabilities underlying the Circular Maturity Tool (CMT) and CE Performance. While the preceding chapters focus on the identification and operationalization of circular capabilities as part of the artifact development process, this chapter deepens and empirically tests these capabilities within a theory-driven model. In line with the DS approach adopted in this thesis, capabilities are iteratively developed across phases, moving from conceptual identification (Chapter 3), to operationalization within the maturity model (Chapter 4), and finally to empirical validation and theoretical refinement in this chapter. The content of this chapter is part of a manuscript in final preparation for submission to the International Journal of Production Research (Wierikx, Ravesteijn, et al., 2026)

5.1 Introduction

The transition to Circular Economy (CE) has become a strategic imperative for addressing global challenges such as resource scarcity, environmental degradation, and unsustainable production systems (Ellen MacArthur Foundation, 2013; Kirchherr et al., 2017).

CE represents a shift from the traditional "take–make–waste" model toward regenerative, closed-loop systems that preserve material value across multiple life cycles (Geissdoerfer et al., 2017). As emphasized by seminal studies on the conceptual foundations of CE (e.g., Geissdoerfer et al., 2017; Kirchherr et al., 2017), it constitutes not merely a set of recycling or efficiency improvements, but a new sustainability paradigm aimed at decoupling economic growth from resource use through design innovation, extended product lifetimes, and value retention strategies. In this way, CE principles such as resource optimization, waste reduction, and system regeneration offer firms opportunities to enhance environmental sustainability and, under specific conditions, to contribute to competitive advantage (Aithal & Aithal, 2023; Liu et al., 2024; Rosário et al., 2024).

Recent policy and market developments, including the EU Circular Economy Action Plan (European Commission, 2020a), the Corporate Sustainability Reporting Directive (CSRD; European Commission, 2021), and increasing ESG-driven investor and consumer pressures (Bocken & Short, 2016; De Jesus & Mendonça, 2018; McKinsey & Company, 2023), have intensified the need for firms to operationalize circularity within their core business models. These developments highlight the growing strategic relevance of developing the organizational capabilities required to implement and scale circular practices effectively. Building on the initial identification and operationalization of these capabilities in earlier chapters, this study further examines how they interact and jointly influence CE Performance in a theory-driven empirical setting.

Despite CE's momentum, many firms still struggle with translating CE principles into practice (Blomsma & Brennan, 2017; Kirchherr et al., 2018; Pigosso & McAloone, 2021). This persistent implementation gap underscores a central managerial and theoretical challenge: identifying which organizational capabilities need to be developed to enable firms to embed circularity systematically across their operations and value chains.

Barriers such as deficiencies in the strategic, operational, collaborative, human, and data-related capabilities required to implement circular principles, together with fragmented knowledge and the absence of actionable strategies, continue to impede circular transitions. These barriers are consistent with prior reviews that highlight knowledge fragmentation, weak inter-organizational collaboration, and capability gaps as persistent obstacles (Cagno et al., 2023; Govindan & Hasanagic, 2018; Pigosso & McAloone, 2021). Based on these insights, Nujen et al. (2023) show that many of these challenges originate internally, as limited learning capacity and intra-organizational knowledge gaps constrain the translation of circular principles into practice. Bressanelli et al. (2019) show that obstacles are particularly evident in circular supply chain transitions, where interdependent operational and coordination challenges reinforce the importance of organizational capabilities and collaboration for effective circular redesign.

Collectively, this body of work indicates that the main impediments to circular transition are not merely technical but also organizational in nature. Firms often lack systematic approaches to diagnose and address the organizational barriers underpinning circular transition, including capability gaps, knowledge fragmentation, and coordination challenges.

Emerging research has responded to the need for more actionable, organizational guidance by highlighting the role of learning- and knowledge-based capabilities as essential enablers of circular transitions (Nujen et al., 2023).

However, although current work underscores the importance of organizational capabilities for circular transition, it remains largely conceptual, often relying on high-level frameworks or small-scale case analyses (e.g., Castillo-Ospina et al., 2025; Khan et al., 2020; Marrucci et al., 2022). Empirically validated, integrative models that explain how interdependent organizational capabilities interact to influence CE Performance remain scarce. For instance, Marrucci et al. (2022) demonstrate that dynamic capabilities indirectly enhance environmental performance through circular practices in certified European firms, yet their work focuses on a specific subset of capabilities and a single performance dimension. Subsequent studies have built on this foundation by emphasizing the relevance of capability configurations for CE Performance (e.g., Chen & Xie, 2022; Franco & Giannoccaro, 2025), but these contributions remain exploratory and context-specific, providing limited empirical evidence of how broader, multi-dimensional configurations of interdependent capabilities affect organizational outcomes. As Khan et al. (2020) also note, further research is needed to test capability-based causal processes quantitatively across diverse organizational contexts and to capture their multidimensional influence on CE Performance outcomes. Only a few studies have attempted to operationalize capability-based constructs within a CE setting (Castillo-Ospina et al., 2025; Chen & Xie, 2022; Franco & Giannoccaro, 2025; Khan et al., 2020; Marrucci et al., 2022), and even fewer have employed structural modeling techniques capable of accounting for interdependencies in multiple capability dimensions (Khan et al., 2020; Marrucci et al., 2022).

In summary, research has yet to provide a comprehensive, empirically validated framework that explains how interdependent capabilities jointly drive CE Performance. This chapter addresses the conceptual limitation, namely the absence of an empirically grounded, multidimensional circular capabilities framework, as well as the methodological limitations arising from prior reliance on conceptual models and small-scale case studies, by empirically testing a multidimensional model of CE capability.

A structured and theoretically grounded perspective is needed to clarify how firms can develop the capabilities required to enhance CE Performance. To address this need, the present research investigates how key organizational capabilities foster CE Performance, offering insight into how firms can translate circular ambitions into measurable outcomes.
Building on Resource-Based View (RBV) (Barney, 1991), this research explores how firms sustain performance in a CE, where effective circular strategies depend on organizational resources and capabilities that are valuable, rare, difficult to imitate, and effectively organized. Not all CE-related resources and capabilities possess these characteristics; many are widely available and easily replicated, contributing primarily to regulatory compliance rather than sustained performance.

However, certain capabilities, such as circular design knowledge, ecosystem collaboration, and data-driven CE measurement, are more firm-specific and difficult to imitate, making them particularly relevant for explaining sustained CE Performance.

Drawing on insights from dynamic capability research in circular contexts (e.g., Marrucci et al., 2022), this study operationalizes a multidimensional CE capability construct that captures the diverse organizational capabilities required to enable circular strategies and to foster CE Performance.

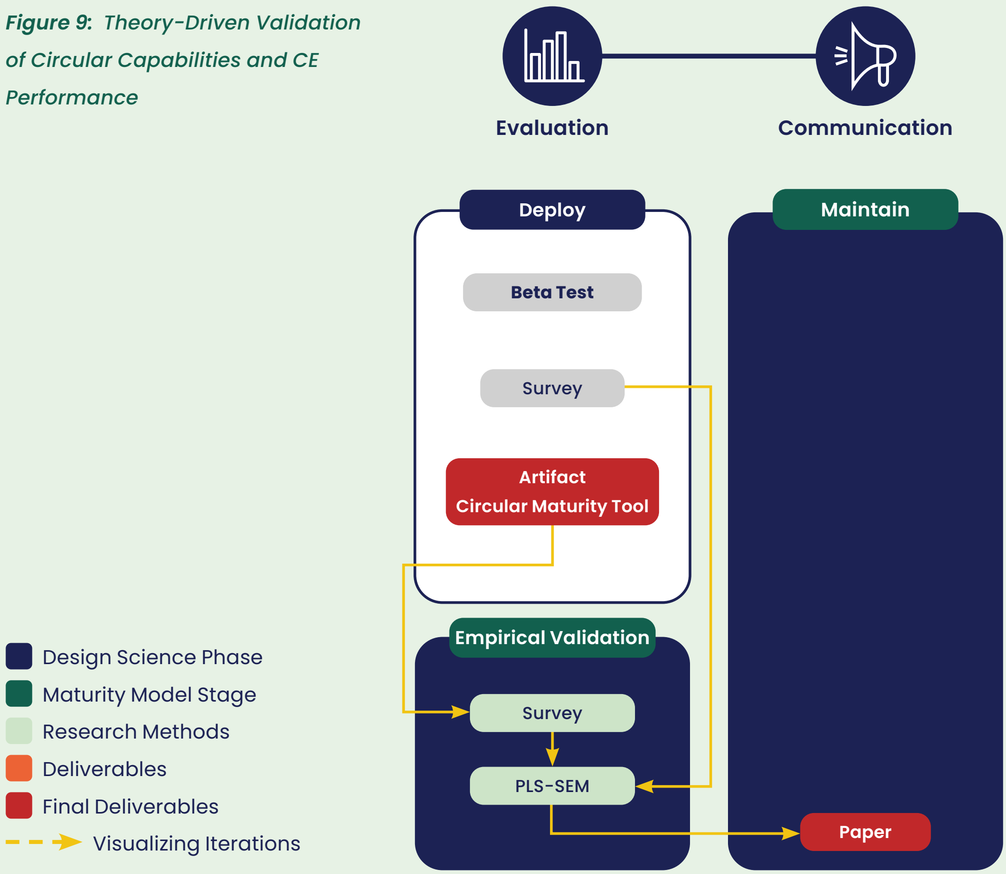
Prior research suggests that organizational capabilities contribute to circular outcomes through specific organizational mechanisms that remain insufficiently integrated and empirically tested in circular contexts (e.g., Khan et al., 2020; Marrucci et al., 2022).

To address this gap, this research conceptualizes CE capability as a multidimensional higher-order construct integrating seven interrelated capability dimensions. Based on prior work (e.g., Khan et al., 2020; Marrucci et al., 2022), CE Performance is modeled as a multidimensional outcome, with organizational capabilities influencing circular outcomes both directly and indirectly. Specifically, the model captures how CE capability fosters CE Performance through two key mechanisms: CE Innovation and CE Products & Services. These constructs represent the primary mechanisms through which organizational capabilities are translated into measurable circular outcomes. Rather than introducing entirely new capability–performance relationships, the contribution of this research lies in integrating established insights into a single, empirically validated system-level model that explains how interdependent organizational capabilities jointly shape CE Performance. This approach provides one of the first empirical examinations of interdependencies among organizational capabilities in circular contexts, thereby contributing to both theoretical refinement and actionable guidance for capability development.

Figure 9 visualizes the theory-driven validation approach adopted in this chapter. It illustrates how the CMT, developed and evaluated in Chapters 3–4, is further examined through a large-scale validation. Specifically, the figure highlights the transition from artifact deployment to theory-driven validation, where survey data are analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to test the relationships between circular capabilities and CE Performance.

Theoretically, this research adopts RBV as an overarching lens to examine how organizational capabilities shape CE Performance. Rather than extending the theory, the research contextualizes recent advances linking dynamic capabilities and circular outcomes (e.g., Khan et al., 2020; Marrucci et al., 2022).

Figure 9: Theory-Driven Validation of Circular Capabilities and CE Performance



This system-level perspective responds to calls in CE supply chain research (e.g., Bressanelli et al., 2019) highlighting the need for integrative frameworks linking circular challenges with organizational and technological levers, as prior research has predominantly focused on interorganizational coordination while offering more limited insight into the firm-level capability systems that enable such coordination (Genovese et al., 2017; Kalmykova et al., 2018).

Practically, the research offers business leaders and sustainability managers actionable insights into how specific capabilities can be developed and aligned to accelerate circular transitions. By mapping the key determinants of CE Performance, the findings offer guidance to firms seeking to align strategic and operational decisions with circularity objectives and broader ESG imperatives (Palea et al., 2024).
In the remainder of this Chapter, Section 5.2 outlines the theoretical background, elaborating on CE principles, RBV, and the role of organizational capabilities.

Section 5.3 presents the conceptual model and hypotheses development. Section 5.4 describes the research methodology, including survey design, data collection, and analysis using PLS-SEM. Section 5.5 reports the results, followed by a discussion of theoretical and managerial implications in Section 5.6. Section 5.7 concludes the Chapter.

5.2 Theoretical Background

5.2.1 Circular Economy

The CE promotes a regenerative business framework that replaces the traditional "end-of-life" notion with strategies aimed at minimizing, repurposing, recycling, and recovering materials throughout the production, distribution, and consumption stages (Kirchherr et al., 2017). By decelerating, closing, and narrowing resource loops, CE encourages firms to redesign manufacturing processes, reconfigure supply chains, and embed circular principles within their core business models (Geissdoerfer et al., 2017).

At the macro level, CE represents a paradigm shift from traditional value creation to restorative and regenerative value systems that preserve material and product value across multiple life cycles (Kortmann & Piller, 2016). Translating these system-level principles into organizational practice, however, requires firms to develop specific capabilities that enable them to redesign processes, coordinate resources, and embed circularity in day-to-day operations. Developing such capabilities is therefore essential for firms seeking to transition successfully to Circular Business Models (CBMs) (Reim et al., 2021; Straub et al., 2023).

The extent to which these capabilities translate into tangible outcomes can be assessed through CE Performance (Uhrenholt et al., 2022). CE Performance is defined as a firm's ability to generate environmental, economic, and social value by effectively implementing circular principles across its operations and value chain (Kristoffersen et al., 2021; Potting et al., 2017; Uhrenholt et al., 2022). This multidimensional view aligns with the triple bottom line perspective (Elkington, 1997) and is widely reflected in CE Performance assessment frameworks (Hubbard, 2009; Kristoffersen et al., 2021). Empirical studies operationalize CE Performance through multidimensional indicators such as resource efficiency, waste reduction, circular design maturity, product lifetime extension, and closed-loop supply chains (Kristoffersen et al., 2021; Uhrenholt et al., 2022).

In the CE literature, R-strategies (e.g., reduce, reuse, recycle, recover – see Table 46) not only structure circular principles, but also operationalize and measure CE Performance, as they reflect the extent to which firms implement circular practices across material flows and product lifecycles (Bocken et al., 2016; Kirchherr et al., 2017; Potting et al., 2017).

Responding to the need for micro-level explanations of how firms build these capabilities, this research adopts an organizational perspective on the CE, focusing on how internal resources and learning mechanisms drive CE Performance (Javaid et al., 2019).

5.2.2 Resource-Based View and Dynamic Capabilities

RBV is a strategic management theory that explains how firms achieve and sustain competitive advantage by leveraging internal resources and capabilities that are valuable, rare, inimitable, and non-substitutable (VRIN) (Barney, 1991). These resources include assets, processes, knowledge, and skills that form the basis for developing organizational capabilities and sustaining competitive advantage (Barney, 1991; Wernerfelt, 1984). Empirical research has shown that firms possessing strong capabilities, such as innovation, knowledge management, and operational flexibility, tend to outperform competitors in various industries (Newbert, 2007; Teece et al., 1997). For example, Newbert (2007) found that firms which effectively bundle and leverage resources achieve superior financial and operational performance, providing empirical evidence for the link between capabilities and competitive advantage.

While RBV offers a foundational explanation of how resources and capabilities create competitive advantage, its classical formulation provides limited guidance for contexts where environmental constraints and sustainability pressures reshape how resources must be combined and reconfigured. Consequently, scholars have extended RBV to address these challenges, most notably through the natural-RBV (Aragón-Correa & Sharma, 2003; Hart, 1995; Russo & Fouts, 1997). This need for theoretical extension is particularly evident in CE contexts, where transitioning to circular systems requires systemic reorientation and the deployment of multiple, interdependent capabilities (Bocken et al., 2016; Geissdoerfer et al., 2018; Ranta et al., 2018).

Building on these theoretical developments, specifically the transition from classical RBV to the natural-RBV and the dynamic capabilities perspective, empirical research has begun to examine how dynamic capabilities (sensing, seizing, and reconfiguring) support the implementation of circular practices.

Khan et al. (2020) provided early evidence that dynamic capabilities facilitate the implementation of CE principles and practices, which in turn enhances firm performance, thereby acting as a mediating mechanism. Their findings underscore that organizational learning and adaptability are critical for translating resource potential into sustainable outcomes, supporting the integration of the dynamic capabilities theory into the natural-RBV.

Drawing on these foundational insights, the dynamic capabilities theory refines RBV by emphasizing that resources alone do not generate sustained advantage unless firms develop the capabilities to combine, coordinate, and reconfigure them in value-creating ways (Amit & Schoemaker, 1993; Teece et al., 1997). Capabilities represent the organizational routines, learning processes, and coordination mechanisms through which resource bundles are transformed into productive outcomes (Teece et al., 1997). Dynamic capabilities extend this logic by explaining how firms renew, realign, and reconfigure their resource base to respond to changing environments (Teece, 2007), an ability that is particularly relevant for CE-oriented transitions.

Beyond higher-level explanations of competitive advantage, dynamic capabilities are grounded in organizational learning processes, developing through iterative mechanisms of knowledge accumulation, articulation, and refinement. As elaborated later, these learning processes are particularly relevant in circular transitions that require continual adaptation and integration across functional and organizational boundaries (Marrucci et al., 2022; Zollo & Winter, 2002).

5.2.3 From Resource-Based to Circular Capabilities

Recent studies demonstrate how resource- and capability-based foundations manifest in CE settings. Prieto-Sandoval et al. (2019) show that competitive advantage in industrial Small and Medium Enterprises (SMEs) arises from an integrated system of resources, competences, and dynamic capabilities that evolve with environmental management maturity. Their findings illustrate that CE implementation depends not merely on resource possession, but on the capability to integrate, learn, and innovate across organizational and inter-organizational levels. This continuity between RBV and the dynamic capabilities theory underpins the conceptual transition to circular capability systems.

Complementing these conceptual advances, prior work has begun to connect dynamic capabilities with circular outcomes. Notably, Marrucci et al. (2022) show that dynamic capabilities enhance environmental performance indirectly via CE practices on European firms.

While this provides important evidence for capability–outcome linkages, their focus is restricted to (i) dynamic capabilities rather than a broader, multidimensional capability system, (ii) certified firms rather than a more heterogeneous sample, and (iii) environ-mental performance as the primary outcome rather than a broader conceptualization of CE Performance. The empirical insights on the role of dynamic capabilities in enabling circular practices and environmental performance align with conceptual work rooted in the natural-RBV.

Hart's natural-RBV, for instance, argues that capabilities related to pollution prevention, product stewardship, and sustainable development are essential for firms aiming to achieve long-term advantage in ecologically constrained environments (Hart, 1995). In CE contexts, prior research suggests that the orchestration of tangible, intangible, and human resources becomes central. Tangible resources include physical and financial assets such as advanced technologies and infrastructure; intangible resources encompass knowledge, organizational culture, and strategic intent; and human resources reflect leadership, skills, and innovation capacity (Barney, 1991; Grant, 1991; Wernerfelt, 1984). Consistent with the dynamic capabilities theory, resources alone are insufficient; firms must be able to reconfigure them in line with CE principles, such as product lifecycle extension, waste minimization, and closed-loop supply chains. Capabilities related to stakeholder engagement and communication also play a critical role in ensuring alignment and transparency throughout the value chain (Bocken et al., 2016; Geissdoerfer et al., 2018; Kazancoglu et al., 2018).

Recent conceptual contributions have advanced RBV–dynamic capabilities theory integration by emphasizing that circular transition relies on both ordinary and dynamic capabilities and their systemic interaction. Lombani et al. (2025) distinguish between ordinary circular capabilities, which enable day-to-day implementation of circular operations, and dynamic circular capabilities, which drive higher-order learning, reconfiguration, and scaling. Building on this layered perspective, Acquier et al. (2024) propose that the scaling of CBMs requires the orchestration of multiple interdependent capability bundles spanning organizational, ecosystemic, and institutional levels. Their work reframes circular advantage as the outcome of capability bundling and integration across these layers, rather than the possession of isolated functional competences.

These studies demonstrate that circular transition depends on the coordination of multiple, mutually reinforcing capabilities that operate across the firm and its wider ecosystem. This evolution, from resource possession in RBV, to resource reconfiguration (dynamic capabilities), to the bundling and alignment of interdependent capability in circular contexts, provides the conceptual foundation for the multidimensional CE Capability construct developed in this research.

5.2.4 CE Capability

Conceptual Foundation Firms aiming to transition to a CE need to develop specific capabilities that facilitate the design, implementation, and scaling of circular practices. Prior research highlights that these organizational capabilities are essential for overcoming circular transition barriers and for embedding circular principles into business operations and strategy (Bressanelli et al., 2019; Kristoffersen et al., 2021).

Recent studies further refine this understanding by emphasizing that circular transition depends on the systemic configuration and orchestration of multiple, mutually reinforcing capabilities. Acquier et al. (2024) describe scaling CBMs as a process of capability layering, where strategic, operational, and ecosystem-level competences co-evolve to support the transition from isolated initiatives to system-wide circularity. Complementing this perspective, Kanda et al. (2025) conceptualize ecosystem orchestration as a meta-dynamic capability that enables firms to align internal routines with inter-organizational collaboration and institutional support structures.

CE Capability is therefore defined as a firm's proficiency in creating, executing, and sustaining circular practices within its operations and throughout its value chain. This conceptualization builds directly on the framework and capability structure developed and operationalized in Chapters 3 and 4, ensuring continuity between artifact development and empirical validation. CE Capability thus represents a multidimensional higher-order construct composed of several interrelated capabilities that together determine a firm's ability to operationalize circular strategies effectively.

Dimensions of CE Capability Consistent with prior research (Kristoffersen et al., 2021; Protogerou et al., 2012), the construct structure adopted in this research reflects both theoretical completeness and parsimony. The seven capability dimensions represent distinct but complementary areas through which firms embed CE principles into strategic orientation, operational practices, and cross-functional processes. The selection of these seven capabilities follows the principle of theoretical parsimony: rather than claiming exhaustiveness, the aim is to capture the core capability dimensions that recur consistently across prior CE and capability-based studies, while avoiding conceptual redundancy (MacKenzie et al., 2011; Whetten, 1989).

Each capability dimension represents a distinct mechanism: strategic orientation (Strategic Capability), human expertise and learning (People & Expertise Capability), cultural support for circularity (Leadership & Culture Capability), operational integration (Operational Capability), stakeholder communication (Marketing & Communication Capability), inter-organizational collaboration (Collaboration Capability), and performance monitoring (Monitoring Capability). Together, these dimensions reflect recurring capability areas identified across CE and capability-based studies, including strategic alignment, operational implementation, cross-functional learning, collaboration, and performance oversight (e.g., Kristoffersen et al., 2021; Merli et al., 2018; Protogerou et al., 2012). In this sense, the seven dimensions synthesize the common patterns emphasized in prior research rather than introduce new or ad hoc categories. Table 25 provides an overview of the seven CE capability dimensions and their definitions.

Table 25: Circular Capabilities

Capability	Description
Strategic Capability	Integrates a circular vision in business policies by embedding CE principles into strategic decision-making, aligning objectives with long-term circularity goals through partnerships, certifications, and reinvestment strategies (de Arroyabe et al., 2021; Merli et al., 2018).
Monitoring Capability	Tracks and measures key CE Performance indicators, ensuring alignment with CE standards through systematic data collection and quality control mechanisms. This includes monitoring emissions, energy use, and resource efficiency to enhance eco-performance and compliance (Kazancoglu et al., 2018).
Collaboration Capability	Facilitates partnerships to optimize resource sharing, drive innovation, and promote collective engagement in circular practices. Strong collaboration enhances product development, sourcing, production methods, and end-of-life management (McKinsey & Company, 2016; Merli et al., 2018).
Leadership & Culture Capability	Establishes an internal culture that supports CE initiatives by fostering innovation, circularity-driven decision-making, and organizational alignment with CE principles (Kwarteng et al., 2022).
People & Expertise Capability	Develops employees' expertise in sustainable design, resource efficiency, and circular supply chain management. Investing in training and knowledge-building is critical for successful CE implementation (Joshi et al., 2020).
Marketing & Communication Capability	Ensures transparency and stakeholder engagement by effectively communicating CE goals, progress, and initiatives to enhance awareness, alignment, and commitment to circularity objectives (Bilal et al., 2020).
Operational Capability	Integrates CE principles in business operations by embedding circular workflows that emphasize waste reduction, resource efficiency, and closed-loop supply chain management. This includes the integration of digital technologies (e.g., IoT, data analytics, and automation) that enable real-time monitoring and coordination of circular processes across the value chain (Garza-Reyes et al., 2019; Rajput & Singh, 2020).

Learning-Based Development of CE Capabilities

Consistent with the learning-based view of dynamic capabilities (Zollo & Winter, 2002), the development of CE Capability can be understood as an outcome of cumulative learning processes. Firms gradually build circular expertise through iterative experimentation, reflection, and codification of successful practices (Nujen et al., 2023; Zollo & Winter, 2002). Feedback-driven learning aligns with the adaptive and evolutionary nature of circular transitions, where capability maturity emerges from deliberate efforts to integrate new knowledge into routines and decision structures (Marrucci et al., 2022).

Empirical studies show that firms with stronger learning and knowledge management routines are better equipped to translate circular principles into performance outcomes (Marrucci et al., 2022; Nujen et al., 2023).

For our research, this perspective clarifies why CE Capability is conceptualized as a multidimensional higher-order construct: it reflects the cumulative, learning-driven nature of capability development, where multiple organizational dimensions mature together not in isolation.

Mechanisms Linking CE Capability to CE Performance
Translating CE Capability into measurable circular outcomes requires understanding the mechanisms through which this capability is manifest in practice. Consistent with capability-based theory, innovation and product–service development represent the principal channels for converting resource-based advantages into sustainable performance (Kristoffersen et al., 2021; Teece, 2007). From a systemic perspective, Kanda et al. (2025) and Acquier et al. (2024) similarly view these mechanisms as the expressions through which orchestrated capabilities yield ecosystem-level outcomes. These insights provide the theoretical rationale for focusing on CE Innovation and CE Products & Services as the two pathways linking CE Capability to CE Performance.

CE Innovation refers to the development of novel products, processes, or business models that enable firms to decouple value creation from resource consumption by promoting reuse, remanufacturing, and closed-loop systems (Bocken et al., 2016; Geissdoerfer et al., 2018). It reflects how firms draw on a broad set of organizational capabilities to redesign production systems, supply chains, and value propositions towards circularity. Empirical studies confirm that innovation-oriented capabilities are central to transforming circular intentions into tangible performance outcomes (Kristoffersen et al., 2021; Sehnem et al., 2022; Triguero et al., 2023).

CE Products & Services represent the market-facing realization of circular innovations. They include product-as-a-service models, remanufactured goods, shared platforms, and other offerings designed to retain value across multiple life cycles (Linder & Williander, 2017; Ranta et al., 2018). In this CE, CE Products & Services are conceptualized as a down-stream manifestation of CE Innovation not an independent capability-driven pathway. Prior empirical research suggests that firms with stronger circular capabilities tend to introduce such offerings more frequently, and that doing so is associated with improved environmental and economic performance (Sehnem et al., 2022; Triguero et al., 2023). These two mechanisms specify how internal capability development is translated into operational and market outcomes, forming the foundation for the conceptual model tested in this research.

5.3 Conceptual Model and Hypotheses Development

Based on the theoretical foundations discussed above, we now develop the conceptual model central to this research, which explains how organizational circular capabilities enable CE Innovation, CE Products & Services, and ultimately CE Performance. Drawing on RBV and its extensions into sustainability contexts, we propose a system of interrelated organizational capabilities that together constitute CE Capability. These capabilities are hypothesized to influence CE Performance both directly and indirectly through key mechanisms.

While the general capability–innovation–performance linkage is well established in prior research (e.g., Barney, 1991; Damanpour, 1991; Teece et al., 1997), its systemic validation within CE contexts remains limited (e.g., Agrawal et al., 2025; Kristoffersen et al., 2021; Ranta et al., 2018). This research contributes by empirically testing a higher-order, CE-specific configuration of capabilities and their combined direct and indirect effects on CE Performance through CE Innovation and CE Products & Services.

Although the seven capability dimensions are conceptually interdependent, this interdependence is precisely what justifies modeling them as a single higher-order construct. Prior research views circular transition as the outcome of orchestrated capability systems rather than isolated functional strengths (e.g., Castillo-Ospina et al., 2025; Kristoffersen et al., 2021; Protogerou et al., 2012). The higher-order operationalization therefore captures the systemic nature of CE capability maturity, reflecting how these dimensions co-evolve and jointly influence CE Innovation, CE Products & Services, and ultimately CE Performance.

To operationalize the CE Capability construct, we identify a set of organizational capabilities that collectively enable the implementation of circular strategies. Building on this conceptual foundation, the model operationalizes CE Capability through seven interrelated dimensions, which are hypothesized to influence CE Performance both directly and indirectly via CE Innovation and CE Products & Services.

To ensure conceptual distinction, CE Capability, CE Innovation, and CE Products & Services are treated as three theoretically distinct constructs. CE Capability captures a firm's internal enablers of circular transition, whereas CE Innovation and CE Products & Services represent mechanisms and market-facing outcomes, respectively. Drawing on RBV, we argue that capabilities alone are not sufficient; they must be translated into innovative processes and concrete circular offerings to generate measurable outcomes.

CE Innovation enhances a firm's ability to reduce resource dependency, extend product lifecycles, and integrate advanced technologies for greater efficiency (Bocken et al., 2016; Geissdoerfer et al., 2017; Rajput & Singh, 2020). In turn, CE Products & Services operationalize these innovations through designs that minimize environmental impact, reduce non-renewable resource consumption, and incorporate end-of-life management and shared-use models (Bocken et al., 2016; Geissdoerfer et al., 2017; Linder & Williander, 2017). Figure 10 presents the proposed conceptual model and its hypotheses. Through these interrelated pathways, circular capabilities indirectly enhance CE Performance by fostering CE Innovation and enabling the development of CE Products & Services.

Furthermore, the conceptual model specifies a directional relationship between the two mechanisms, whereby CE Capability enables CE Innovation, which subsequently supports the development of CE Products & Services. These relationships are modeled as distinct yet interrelated pathways within the broader capability–innovation–performance system. All hypothesized relationships are examined simultaneously to capture both direct and indirect associations, not as a single serial mediation chain.

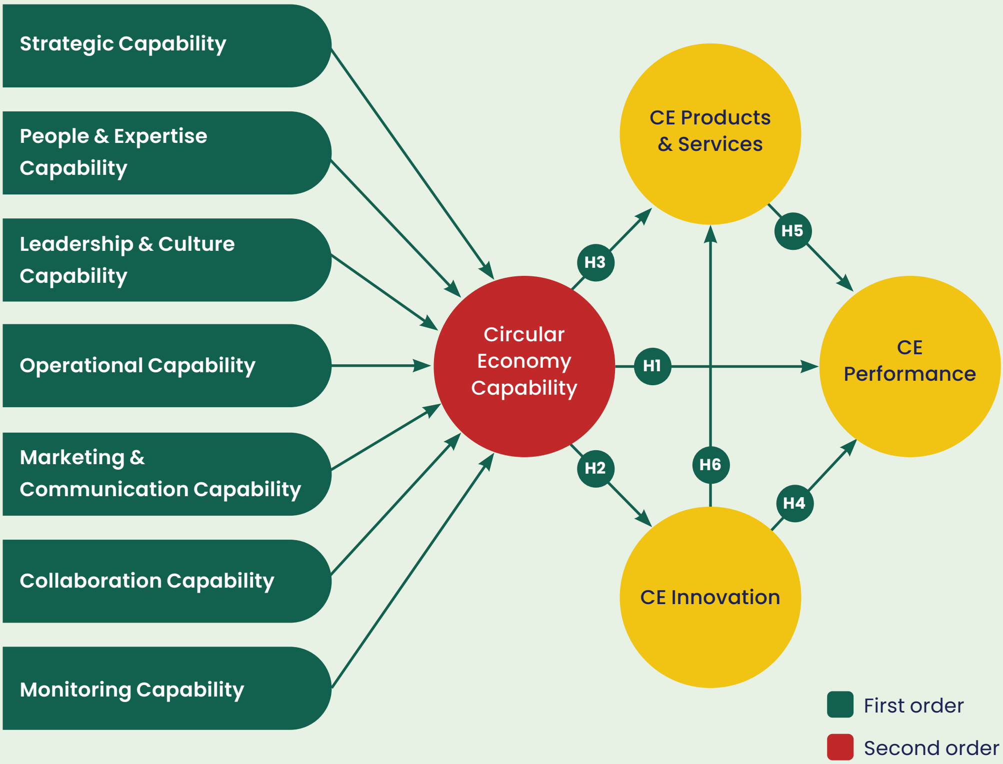
5.3.1 CE Capability and CE Performance

Recent studies continue to highlight the central role of organizational capabilities in enabling circular transitions and performance (Agrawal et al., 2025; Franco & Giannoccaro, 2025; Saari et al., 2024). The seven interrelated organizational capabilities that comprise CE Capability (see Table 25) build on established frameworks from prior research (Castillo-Ospina et al., 2025; De Angelis et al., 2023), as well as the dimensions outlined in Chapters 3 and 4 of this dissertation. These capabilities contribute to CE Performance in complementary ways: strategic, leadership, and people-related capabilities align decision-making and culture with circular goals; operational and monitoring capabilities embed circular workflows and support continuous improvement; and collaboration and marketing & communication capabilities enable resource sharing, transparency, and ecosystem coordination (Garza-Reyes et al., 2019; Geissdoerfer et al., 2018; Kazancoglu et al., 2018). These contributions are well supported by empirical evidence (Geng et al., 2012; Kazancoglu et al., 2018; Zils et al., 2023).

Both prior theoretical and empirical insights indicate that CE Capability constitutes a critical organizational foundation for achieving superior CE Performance. Firms with well-developed capability systems are better able to embed circular principles across their operations and value chains, generating measurable improvements in circular outcomes. Thus, we hypothesize:

H1: CE Capability positively influences CE Performance.

Figure 10: Conceptual Model



5.3.2 CE Capability and CE Innovation

In this research, CE Innovation encompasses product, process, and business model innovations that operationalize circular principles. Product innovations include design for durability, repairability, and reuse; process innovations involve resource-efficient production and waste recovery; and business model innovations refer to the conceptualization and early-stage development of service-based, sharing, or take-back models that support the transition to circular offerings. These models, once market-ready, are further captured under CE Products & Services. This multidimensional perspective ensures that CE Innovation captures both technological and organizational change mechanisms essential for circular transition (Bocken et al., 2016; Geissdoerfer et al., 2018).

CE Capability provides the strategic and operational foundation upon which CE Innovation can emerge and scale. The Strategic, Collaboration, Operational, Monitoring, and Leadership & Culture Capabilities establish the necessary infrastructure for experimentation, learning, and the diffusion of circular solutions (Bocken et al., 2016; Geissdoerfer et al., 2018; Kazancoglu et al., 2018).

Within the Operational Capability dimension, digital integration contributes to CE Innovation by enabling data-driven coordination and improved process efficiency, which create conditions for experimentation and developing circular solutions (Rajput & Singh, 2020). The Leadership & Culture Capability fosters a learning-oriented mindset and openness to experimentation, while the Monitoring Capability provides data-driven feedback for continuous refinement and improvement.

Digital technologies such as the Internet of Things, real-time analytics, and automation further reinforce CE Innovation by enabling predictive maintenance, resource tracking, and closed-loop production systems (Rajput & Singh, 2020; Zils et al., 2023). Marketing and Communication Capability complements these efforts by aligning internal and external stakeholders, enhancing transparency, and fostering engagement with circular strategies (Bilal et al., 2020; Kazancoglu et al., 2018). While specific dimensions were highlighted, it is their joint, systemic interplay that enables CE Innovation.

From a theoretical standpoint, RBV and dynamic capabilities theory together explain how organizational capabilities drive innovation. According to RBV, firms gain a competitive advantage by developing and leveraging VRIN resources (Barney, 1991). CE Capability functions as such a strategic resource, enabling firms to develop and deploy circular innovations by effectively mobilizing and integrating organizational knowledge, processes, and technologies. Dynamic capabilities theory extends this logic by emphasizing a firm's ability to adapt, integrate, and reconfigure internal resources in response to environmental change (Teece et al., 1997). In CE contexts, this involves developing systemic innovations such as closed-loop supply chains, digital platforms, and collaborative ecosystems (Geng et al., 2012).

Existing empirical studies provide valuable indications that specific capability dimensions, such as dynamic capabilities, collaboration, or digital integration, can stimulate particular forms of circular innovation (Bocken et al., 2016; Geissdoerfer et al., 2018; Rajput & Singh, 2020; Zils et al., 2023).

These mechanisms indicate that the CE Capability establishes the organizational conditions required for developing and scaling circular innovations. Building on this theoretical foundation, we hypothesize:

> ***H2: CE Capability positively influences CE Innovation.***

5.3.3 CE Capability and CE Products & Services

A strong CE Capability equips firms with the expertise, technologies, and strategic frameworks required to develop circular products and services that emphasize circular outcomes (e.g., extended lifecycles and resource efficiency). Circular offerings maximize resource efficiency, extend product lifecycles, and minimize waste throughout their use phases (Bocken et al., 2016; Linder & Williander, 2017). Examples include durable and repairable product designs, remanufacturing strategies, and service-based models (Stahel, 2016). Developing such offerings requires firms to cultivate and integrate specific circular capabilities. Each underlying CE capability dimension contributes to the development of circular products and services in complementary ways. Strategic Capability ensures that circularity is embedded in long-term business planning, aligning product development with circularity goals (Bocken et al., 2016; Geissdoerfer et al., 2018). Collaboration Capability fosters partnerships among suppliers, consumers, and other stakeholders, facilitating the optimization of material flows and joint value creation (Bocken et al., 2016). Monitoring Capability allows firms to track environmental impact metrics and ensure continuous improvement in product design and lifecycle management (Kazancoglu et al., 2018). Leadership & Culture Capability reinforces circular implementation by promoting a circularity-driven mindset and empowering employees to pursue innovative solutions (Kristoffersen et al., 2021; Kwarteng et al., 2022). Operational Capability embeds circular principles in core business processes, enabling efficient resource use, closed-loop production, and scalable waste reduction initiatives. These capabilities also support the integration of technologies such as remanufacturing, modular production, and reverse logistics that are critical for delivering circular offerings (Rajput & Singh, 2020; Stahel, 2016). People & Expertise Capability develops and mobilizes the human capital needed to drive circular innovation and implementation. By investing in employee training, cross-functional collaboration, and knowledge-sharing practices, firms cultivate the competencies required to translate circular ambitions into concrete outcomes (Garza-Reyes et al., 2019; Ranta et al., 2018). Finally, Marketing & Communication Capability raises awareness, educates stakeholders, and positions circular offerings competitively in the market by communicating their benefits, such as cost savings, durability, and lower environmental impact (Bilal et al., 2020; Merli et al., 2018).

From a RBV perspective, circular products and services are the outcomes of how firms deploy their circular capabilities. These capability configurations draw on firm-specific knowledge and integrated routines that guide circular design and development. For instance, electronics companies investing in modular product design enable component replacement instead of product disposal, creating value through lifecycle extension and cost reduction. These configurations rely on firm-specific integration of design and supply chain routines, making them difficult for competitors to imitate.

Similarly, automotive manufacturers applying remanufacturing strategies recover and refurbish components, reduce material use and build unique operational routines that reinforce competitive advantage (Bocken et al., 2016; Ranta et al., 2018).

Beyond individual products, firms with strong circular capabilities implement sustainable supply chain practices, such as take-back systems, reverse logistics, and closed-loop production, that support material recovery and enable remanufacturing or recycling (Genovese et al., 2017; World Economic Forum, 2021).

Empirical studies illustrate how CE Capability supports the development of circular products and services. For instance, Urbinati et al. (2017) show that firms with well-developed organisational and strategic capabilities are more likely to implement circular business model configurations, resulting in service-based offerings, extended product life-cycles, and resource-efficient solutions. Recent large-scale evidence further confirms the central role of products and services as a distinct domain of circular economy implementation across firms (Bocken et al., 2025). Together, these mechanisms show that circular capabilities provide the organizational basis for designing and developing circular products and services. Accordingly, we hypothesize:

H3*: *CE Capability positively influences CE Products & Services.

5.3.4 CE Performance Mechanisms: Innovation and Products & Services

Previous research provides extensive empirical support for the positive relationship between CE Innovation, CE Products & Services, and CE Performance (e.g., Bocken et al., 2016; Geissdoerfer et al., 2018; Ghisellini et al., 2016).

Building on this theoretical foundation, we examine CE Innovation and CE Products & Services as complementary mechanisms through which organizational capabilities translate into CE Performance.

CE Innovation and CE Performance

CE Innovation enables firms to continuously improve circular practices, enhance resource efficiency, and adapt operational models, all contributing to superior CE Performance. Prior research highlights innovation as a key driver of waste reduction, product lifetime extension, and process optimization, positioning it as an essential mechanism for circular success (Bocken et al., 2016; Geissdoerfer et al., 2017).

Empirical studies consistently demonstrate innovation's central role in advancing circularity and performance outcomes. For example, Geissdoerfer et al. (2018) emphasize that CBMs inherently depend on innovation.

Particularly in integrating supply chains and product–service systems, while Ghisellini et al. (2016) show that product and process innovations significantly enhance both environmental and economic performance. Similarly, Bocken et al. (2016) highlight that innovation-driven circular practices reduce costs, improve resource efficiency, and enhance brand reputation.

Theoretically, this link is consistent with dynamic capabilities theory, which views innovation as a firm's ability to adapt, integrate, and reconfigure resources in response to changing environments (Teece et al., 1997; Teece, 2010). In circular contexts, such adaptability enables firms to improve resource utilization, enhance loop-closing practices, and achieve superior CE Performance.

Collectively, these findings indicate that CE Innovation is a pivotal mechanism for firms to translate capability strength into measurable CE Performance gains. Accordingly, we hypothesize:

H4: CE Innovation positively influences CE Performance.

CE Products & Services and CE Performance CE Products & Services represent the tangible manifestations of circularity in a firm's market offerings. They reflect how circular principles are embedded into product design, use phases, and end-of-life strategies, enabling firms to close, slow, and narrow resource loops (Bocken et al., 2025; Bocken et al., 2016).

Through closing loops, materials are continuously reused or recycled, preventing resource leakage and reducing dependency on virgin resources. Slowing loops extends product lifetimes through maintenance, refurbishment, and reuse, thereby minimizing waste generation. Narrowing loops increases resource efficiency by optimizing product design and production processes (Bocken et al., 2016). Together, these mechanisms reinforce the CE's restorative logic by maximizing resource utility and minimizing environmental impact.

These systems embed circular principles across the value chain and foster a lifecycle perspective that supports remanufacturing, reuse, and recycling (Geissdoerfer et al., 2017; Rajput & Singh, 2020). Similarly, Zils et al. (2023) demonstrate that circular product strategies improve resource security, reduce reliance on virgin materials, and generate cost savings through enhanced material efficiency.
Rather than referring to the capabilities that enable such offerings, this construct captures the extent to which circularity is materialized in the products and services delivered to the market.

As market-facing manifestations of circularity, CE Products & Services directly enhance CE Performance by reducing waste, improving resource efficiency, and generating economic value (Geissdoerfer et al., 2017; Kirchherr et al., 2017). Firms that effectively design, market, and manage such offerings are therefore expected to achieve superior outcomes. Environmentally, they reduce material consumption and waste disposal costs; economically, they realize cost savings and higher operational efficiency (Ghisellini et al., 2016; Kirchherr et al., 2017). Compliance with environmental regulations, such as extended producer responsibility and carbon reduction targets, further reduces long-term operational risk and enhances stakeholder trust (Geissdoerfer et al., 2017). By integrating circular products and services into their operations, firms close material loops and align economic, environmental, and social objectives. Accordingly, we hypothesize:

H5: CE Products & Services positively influences CE Performance.

5.3.5 CE Innovation and CE Products & Services

CE Innovation plays a pivotal role in enabling firms to develop circular products and services by fostering sustainable design, optimizing resource use, and promoting lifecycle-oriented business practices. Within this research, CE Innovation operates as the dynamic mechanism through which the potential embedded in CE Capability is converted into tangible circular offerings. This interpretation aligns with dynamic capabilities theory, which views innovation as a bridging process that transforms organizational resources and routines into market-facing outcomes (Teece et al., 1997; Teece, 2010). Hence, CE Innovation is conceptualized as a direct determinant of CE Products & Services within the broader capability–innovation–performance system.

The conceptual framework builds on dynamic capabilities theory (Teece, 2007; Teece et al., 1997), which posits that organizational capabilities alone do not directly lead to outcomes. Rather, they provide the foundation for innovation processes that reconfigure resources and routines to generate new products, services, and business models. In this view, CE Innovation serves as the mechanism that translates the potential embedded in CE Capability into tangible circular outcomes.

Consistent with prior CE research, CE Innovation acts as the key mechanism translating organizational capabilities into concrete circular products and services (Bocken et al., 2025; Bocken et al., 2016; Geissdoerfer et al., 2018; Ranta et al., 2018).

Hence, CE Innovation facilitates the translation of CE Capability into CE Products & Services because it represents the process of transforming strategic intent and resource configurations into concrete circular offerings.

Through innovation, firms translate circular design principles into concrete offerings that reflect lifecycle extension, resource efficiency, and closed-loop value creation (Bocken et al., 2014; Geissdoerfer et al., 2018). Rather than examining specific innovations for their direct performance impact, this relationship focuses on how CE Innovation materializes circular principles into concrete products and services (Antikainen et al., 2018; Bocken et al., 2016).

Empirical studies demonstrate that firms leveraging innovation in product design and manufacturing processes are more likely to develop effective circular offerings, reinforcing the role of CE Innovation in enabling CE Products & Services (Bocken et al., 2016). Geissdoerfer et al. (2018) further show that circular innovation enhances lifecycle value creation and addresses resource inefficiencies, while Bocken et al. (2014) highlight its importance for the successful development of circular products and services.

Accordingly, CE Innovation is expected to positively influence to what extent firms introduce and scale CE Products & Services. We therefore hypothesize:

> ***H6*: *CE Innovation positively influences CE Products & Services.***

5.4 Research Method

5.4.1 Measurement Instrument

To measure the constructs and their influence on CE Performance, we designed a survey instrument. The measurement model builds on the validated CMT, which encompasses multiple interrelated organizational capabilities, and was developed through a multi-stage DS process, as detailed in Chapters 3 and 4. These chapters detail the developmental validation, but all constructs were independently revalidated empirically in this study following established PLS-SEM procedures for reliability, convergent validity, and discriminant validity (Hair et al., 2021). This ensures that the measurement model is fully validated within the context of the present dataset.

Items (see Appendix K) were adapted from established scales in the strategic management and CE literature and subsequently contextualized for the CE dimension (e.g., Garza-Reyes et al., 2019; Kazancoglu et al., 2018; Kristoffersen et al., 2021; Pigosso & McAloone, 2021). Content validity was established through expert evaluation by CE scholars and practitioners, who assessed item clarity, relevance, and conceptual fit. Construct validity was then examined through confirmatory assessment of reliability, convergent validity, and discriminant validity (see Table 28).

The DS validation process followed the Design Science Validity Framework (DSVF) (Larsen et al., 2025), where criterion and context validity were established through expert panels (alpha stage – v1), and causal validity through quantitative and qualitative testing (beta stage – v2). The present study evaluated the final version of the measurement model (v3) using survey data collected between March 2024 and October 2025, distinct from the data used in the earlier validation stages described in Chapters 3 and 4. Reliability and validity thresholds were met for all constructs, with Cronbach's alpha (CA > 0.70) indicating internal consistency reliability, average variance extracted (AVE > 0.50) supporting convergent validity, and the heterotrait-monotrait ratio of correlations (HTMT < 0.85) confirming discriminant validity. Appendix K lists all measurement items.

Ten constructs were operationalized: *Strategic Capability, People & Expertise Capability, Leadership & Culture Capability, Operational Capability, Marketing & Communication Capability, Collaboration Capability, Monitoring Capability, CE Products & Services, CE Innovation*, and *CE Performance* (see chapters 3 and 4 for more details).

In line with established CE assessment frameworks, CE Performance was operationalized using R-strategies (e.g., reduce, reuse, recycle, recover) following Potting et al. (2017). These strategies capture to what extent circular principles have been implemented across material flows and product lifecycles and enable the translation of multidimensional CE Performance concepts into empirically observable indicators suitable for PLS-SEM analysis. Table 46 presents the R-strategies as defined by Potting et al. (2017). Table 26 summarizes the item counts and underlying sources.

Table 26: Overview of Items for all Constructs

Construct	No. of Items	Based on
Strategic Capability	14	Ioannou et al. (2016), Ormazabal et al. (2016), Pigosso and McAloone (2021), and WBCSD (2018)
People & Expertise Capability	6	Masi et al. (2018), Pigosso and McAloone (2021), Rudd et al. (2018), and Uhrenholt et al. (2022)
Leadership & Culture Capability	6	Hollins (2019), Jun et al. (2006), and Wierikx, Raassens, et al. (2026)
Operational Capability	8	Kazancoglu et al. (2018) and Wierikx, Raassens, et al. (2026)
Marketing & Communication Capability	4	Fonseca et al. (2018) and Kazancoglu et al. (2018)
Collaboration Capability	8	Fonseca et al. (2018), Garza-Reyes et al. (2019), Ioannou et al. (2016), and Verbeek (2016)

Table 26: Overview of Items for all Constructs – Continued

Construct	No. of Items	Based on
Monitoring Capability	13	Kazancoglu et al. (2018), Masi et al. (2018), Mura et al. (2020), and Ormazabal et al. (2016, 2018)
CE Products & Services	12	Garza-Reyes et al. (2019), Mura et al. (2020), Ormazabal et al. (2018), and Pigosso and McAloone (2021)
CE Innovation	5	Calik et al. (2017), Garza-Reyes et al. (2019), and Pigosso and McAloone (2021)
CE Performance	10	Potting et al. (2017)

For all items a seven-point Likert scale was used, ranging from 1 (*Strongly Disagree*) to 7 (*Strongly Agree*), consistent with psychometric guidelines (Oaster, 1989; Preston & Colman, 2000).

5.4.2 Data Collection and Sample

Senior managers and decision-makers were targeted for data collection. A mixed sampling strategy was used: purposive sampling was employed to reach firms known to be engaged in circular practices, followed by an open-access dissemination strategy to broaden participation across firms with varying levels of circular maturity. This ensured sample heterogeneity while maintaining relevance to the constructs under investigation. As in similar exploratory PLS-SEM studies, some degree of self-selection bias is possible but acceptable (Hair et al., 2021). Limitations are discussed in Section 5.6.4.

In total, 491 valid responses were obtained from 329 organizations. Of these, 282 organizations (85.7%) provided a single response, while 47 organizations (14.3%) provided multiple responses (209 additional responses). Multiple responses were retained because they represent distinct managerial perspectives across business units, which is particularly relevant in the context of cross-functional circular capabilities. Some organizations also operate geographically dispersed units, further reducing within-firm dependencies.

The respondents were involved in product redesign, circular business model development, and take-back initiatives. Table 27 summarizes the respondent sample statistics. Respondents' roles included senior management (30%), middle management (44%), and technical/operational functions (26%). Firms represented manufacturing (41%), logistics (17%), energy/utilities (13%), and service sectors (29%), with 65% SMEs and 35% large firms.

Table 27: Respondent Sample Statistics

Characteristic	Distribution
Respondent position	30% senior management, 44% middle management, 26% technical/operational
Firm size	65% SMEs (<250 employees), 35% large firms
Industry sector	41% manufacturing, 17% logistics, 13% energy/utilities, 29% services
Geographic coverage	100% the Netherlands

5.4.3 Missing Data Analysis

Missing values accounted for less than 3% of all responses. Visual inspection showed no systematic pattern between missingness and respondent or firm characteristics. Little's MCAR test (Little, 1988) indicated that the data were not Missing Completely At Random (X^2 = 15,355.607; df = 13,830; $p < 0.05$), rendering listwise deletion inappropriate (Enders, 2022; Liu et al., 2025).
Expectation–Maximization (EM) imputation was applied to survey items with up to 15% missingness. This applied to eight items across multiple constructs. EM preserves co-variance structures and is well suited for PLS-SEM applications (Liu et al., 2025; Schafer, 2002). Two items exceeded the 15% threshold (C5 and M20, Appendix K, Tables 49 and 56) and were removed to protect construct reliability (Enders, 2022). This approach ensured a robust and theoretically consistent treatment of missing data.

5.4.4 Measurement Validation

Measurement quality was assessed using established criteria for reflective measurement models in PLS-SEM (Hair et al., 2021). Reliability was confirmed through CA and composite reliability (CR) values above 0.70 for all constructs. Convergent validity was supported by AVE values above 0.50, and discriminant validity was confirmed through HTMT values below the conservative 0.85 threshold. These results confirm that the measurement model demonstrates adequate reliability, convergent validity, and discriminant validity, providing a solid foundation for structural model estimation.

5.4.5 Ethical Considerations and Common Method Bias

All respondents were informed about the CE's objectives, the voluntary nature of participation, and the confidentiality of their responses. Anonymity was ensured in compliance with established ethical guidelines (Resnik, 2020).
Because independent and dependent variables were collected through the same survey instrument, procedural and statistical remedies were implemented to reduce the risk of common method bias (CMB) (Podsakoff et al., 2003). Procedural safeguards included ensuring respondent anonymity.

Statistical tests indicated that CMB was unlikely to bias the results. Harman's single-factor test showed that the first factor accounted for 37.39% of total variance, below the conventional 50% threshold. Moreover, full collinearity VIF values for all latent constructs were below 3.3 (Kock, 2015), providing additional evidence that CMB does not pose a threat to the validity of the findings.

5.5 Analysis and Results

5.5.1 Measurement Model

Given that the model includes reflective and formative constructs, distinct evaluation criteria were applied to both. Consistent with the validation procedures outlined in the measurement development section, the first-order reflective latent constructs were examined with regard to reliability, convergent validity, and discriminant validity. At the construct level, both CR and CA values exceeded the recommended threshold of 0.70, confirming satisfactory internal consistency across all reflective constructs (Hair et al., 2021). Convergent validity was established by ensuring that the AVE values exceeded the minimum threshold of 0.50. Discriminant validity was assessed using the HTMT ratio, which has been shown to outperform earlier methods (Henseler et al., 2015); all HTMT values were below 0.90, indicating adequate discriminant validity. These findings (see Table 28) demonstrate that the reflective measures have sufficient validity and are appropriate for further analysis.

***Table 28**: Assessment of Reliability, Convergent, and Discriminant Validity of the Reflective Constructs*

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
(A) Strategic Capability										
(B) People & Expertise Capability	0.730									
(C) Leadership & Culture Capability	0.810	0.868								
(D) Operational Capability	0.697	0.751	0.729							
(E) Marketing & Communication Capability	0.853	0.796	0.803	0.718						
(F) Collaboration Capability	0.795	0.706	0.794	0.729	0.840					
(G) Monitoring Capability	0.614	0.498	0.474	0.649	0.549	0.590				
(H) CE Products & Services	0.721	0.728	0.773	0.683	0.724	0.814	0.504			
(I) CE Innovation	0.741	0.761	0.753	0.705	0.814	0.804	0.556	0.856		

Table 28: Assessment of Reliability, Convergent, and Discriminant Validity of the Reflective Constructs – Continued

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
(J) CE Performance	0.628	0.607	0.617	0.638	0.605	0.644	0.493	0.714	0.704	
Cronbach's Alpha (CA)	0.887	0.804	0.876	0.841	0.862	0.868	0.844	0.851	0.713	0.870
Composite Reliability (CR)	0.891	0.807	0.878	0.847	0.863	0.874	0.866	0.852	0.735	0.871
Average Variance Extracted (AVE)	0.639	0.630	0.669	0.613	0.783	0.657	0.677	0.627	0.634	0.524

The higher-order CE Capability construct was modeled as a formative construct composed of seven first-order reflective capability dimensions. To assess collinearity among these formative indicators, the Variance Inflation Factor (VIF) was examined. As shown in Table 29, three indicators displayed VIF values slightly above the commonly referenced threshold of 3.0 (ranging from 3.075 to 3.215). While these values suggest moderate collinearity, they remain well below the less conservative thresholds of 5 or 10 that are typically used to signal serious multicollinearity problems (Hair et al., 2021). Elevated VIF values are not uncommon in reflective–formative type II hierarchical models, where conceptually related first-order dimensions share substantial variance (Becker et al., 2012; Sarstedt et al., 2016). In this context, such collinearity does not undermine construct validity but warrants cautious interpretation of indicator weights (Diamantopoulos & Siguaw, 2006).

Then we examined the formative indicators' weights and loadings. Several indicator weights were non-significant, which is not unusual in formative specifications (Cenfetelli & Bassellier, 2009). In such cases, the absolute contribution of the indicator can be evaluated using its loading. According to Hair et al. (2021), indicators with non-significant weights may be considered for removal if their loadings fall below 0.50. In this analysis, all indicators exhibited loadings above 0.50 (ranging from 0.690 to 0.862), indicating that each dimension makes a meaningful contribution to the higher-order CE Capability construct. Consequently, no indicators were removed, and the formative specification retained both empirical adequacy and theoretical coherence in capturing distinct yet interdependent capability dimensions.

Table 29: Assessment of VIF, Significance, and Relevance of the Formative Constructs' Indicator Weights

	VIF	Weight	Significance	Loading
Strategic Capability	3.075	-0.171	n.s.	0.690
People & Expertise Capability	2.604	0.390	$p<0.05$	0.791
Leadership & Culture Capability	3.215	-0.109	n.s.	0.691
Operational Capability	2.269	0.050	n.s.	0.740
Marketing & Communication Capability	3.138	0.135	n.s.	0.773
Collaboration Capability	2.788	0.471	$p<0.10$	0.862
Monitoring Capability	1.663	0.425	$p<0.01$	0.796

This interpretation aligns with the learning-based view of dynamic capabilities development (Zollo & Winter, 2002), which emphasizes that organizational routines evolve through iterative learning. The observed formative structure of CE Capability reflects both the distinctiveness of capability dimensions and their integration in higher-order patterns via such learning processes. This learning-based perspective strengthens the rationale for retaining all formative indicators despite variations in individual weight significance, as each dimension represents a path-dependent learning trajectory that cumulatively contributes to overall CE Capability maturity.

5.5.2 Structural Model

The structural model focuses on the hypothesized relationships among CE Capability, CE Innovation, CE Products & Services, and CE Performance. Although firm size and industry were included in the descriptive analysis, they were not incorporated into the structural model. To maintain theoretical parsimony and avoid unnecessary model complexity, these factors were captured through sample heterogeneity, not explicitly incorporated into the structural model (Hair et al., 2021).

Construct-level VIF values ranged from 1.000 to 2.786, all well below the commonly accepted threshold of 5 (and even the more conservative threshold of 3.3), indicating the absence of problematic multicollinearity (Hair et al., 2021).

Although mediation was not specified as a formal hypothesis, all direct paths among the constructs were estimated simultaneously. This modeling strategy allows indirect effects to emerge where theoretically plausible and balances theoretical parsimony with explanatory completeness (Sarstedt et al., 2019).

Table 30: Model Estimates

Hypothesis	Path coefficient	*t*-statistic	*p*-value	95% confidence intervals (two-tailed)	*f* 2 effect size	Result
H1: CE Capability > CE Performance	0.338	5.412	p <0.01	[0.221; 0.463]	0.078	Supported
H2: CE Capability > CE Innovation	0.718	28.950	p <0.01	[0.667; 0.764]	1.063	Supported
H3: CE Capability > CE Products & Services	0.541	10.467	p <0.01	[0.441; 0.641]	0.350	Supported
H4: CE Innovation > CE Performance	0.153	2.555	p <0.01	[0.031; 0.266]	0.020	Supported
H5: CE Products & Services > CE Performance	0.268	4.432	p <0.01	[0.149; 0.388]	0.055	Supported
H6: CE Innovation > CE Products & Services	0.285	5.010	p <0.01	[0.172; 0.393]	0.097	Supported

Table 30 summarizes the structural path estimates, including path coefficients, *t*-statistics, *p*-values, confidence intervals, effect sizes, and hypotheses test results.

As shown in Table 30, all the hypothesized relationships are statistically significant and in the expected direction. Hypothesis H1 (CE Capability > CE Performance) is supported with a path coefficient of 0.338 (t = 5.412, $p < 0.01$) and a moderate f^2 effect size of 0.078. H2 (CE Capability > CE Innovation) shows the strongest relationship, with a path coefficient of 0.718 (t = 28.950, $p < 0.01$) and a large f^2 effect size of 1.063. H3 (CE Capability > CE Products & Services) is also supported, with a path coefficient of 0.541 (t = 10.467, $p < 0.01$) and an f^2 effect size of 0.350. H4 (CE Innovation > CE Performance) reveals a weaker but still significant effect (path coefficient = 0.153, t = 2.555, $p < 0.01$, f^2 = 0.020). H5 (CE Products & Services > CE Performance) shows a significant relationship, with a path coefficient of 0.268 (t = 4.432, $p < 0.01$) and an f^2 of 0.055. Finally, H6 (CE Innovation > CE Products & Services) is supported (path coefficient = 0.285, t = 5.010, $p < 0.01$, f^2 = 0.097).

Among the hypothesized relationships, CE Capability exhibits the highest standardized coefficient toward CE Innovation (ß = 0.718), followed by a strong effect on CE Products & Services (ß = 0.541). This pattern is consistent with the theorized role of capabilities as enabling mechanisms that drive innovation and product–service development.

In line with Vaithilingam et al. (2024), several diagnostic and robustness checks were conducted to ensure the validity of the PLS-SEM results. These procedures included (1) an assessment of data normality, (2) robustness checks for potential endogeneity, and (3) tests for non-linearity in the structural relationships.

First, to evaluate normality, we examined skewness and kurtosis values. According to Hair et al. (2021, p. 66), values within the range of -1 to +1 are ideal, while those between -2 and +2 are typically acceptable, particularly given PLS-SEM's tolerance for non-normal data distributions. In this research, skewness values ranged from -1.096 to 0.402, and kurtosis values between -1.291 and 0.901, indicating that non-normality was not an issue.

Second, to assess potential endogeneity in the structural model, we applied the Gaussian Copula method to all structural relationships (Hult et al., 2018; Park & Gupta, 2012), which is appropriate for PLS-SEM models with potentially non-normally distributed predictors. The Gaussian Copula procedure tests whether the predictors contain a non-linear component associated with the residuals, indicating potential endogeneity. Among the tested paths, only the relationship between CE Capability and CE Products & Services showed a significant Copula term, suggesting the presence of endogeneity. For all other relationships, the Copula terms were non-significant. Although the Copula term for the CE Capability › CE Products & Services path was significant, the structural path remained significant both before and after inclusion of the Copula correction. This indicates that the observed effect is robust and not solely attributable to endogeneity. We therefore uphold our conclusion that higher CE Capability contributes to greater development of CE Products & Services.

Third, as part of the robustness checks for the structural model, we additionally assessed whether the estimated relationships exhibit non-linear patterns by including quadratic terms in the model (Basco et al., 2022). The quadratic terms for the relationships CE Products & Services › CE Performance and CE Capability › CE Performance were significant, indicating the presence of curvilinear effects. Importantly, the corresponding linear effects remained significant when the quadratic terms were included, suggesting that the effects are robust but may vary in magnitude across different levels of CE Products & Services and CE Capability.

Thus, the robustness checks indicate that the positive impact on CE Performance may vary across the range of predictor values, although the linear effects remain statistically significant. Given that non-linearity was not hypothesized ex ante, these results are interpreted as indicative patterns rather than definitive curvilinear relationships.

The explanatory strength of the model provides empirical support for the theorized capability-based relationships among the constructs. The model explains 59.5% of the variance in CE Products & Services, 51.5% in CE Innovation, and in particular 47.3% in CE Performance, representing a moderate yet meaningful level of explanatory power for a multidimensional PLS-SEM model. This result is consistent with the range typically reported in comparable CE capability studies (e.g., Khan et al., 2020; Marrucci et al., 2022) and aligns with interpretation guidelines by Hair et al. (2021), where R^2 values of approximately 0.25, 0.50, and 0.75 correspond to weak, moderate, and substantial ex-planatory strength, respectively. Given the complexity of the model and the behavioral and contextual heterogeneity inherent in organizational research, the obtained R^2 should be regarded as respectable rather than exhaustive. This suggests that additional con-textual or organizational factors, such as regulatory pressures, industry characteristics, or firm maturity, may further influence CE Performance beyond those included in the present CMT. Nevertheless, the observed explanatory power provides a robust foundation for theory testing and supports the relevance of the capability-based model within the scope of this research.

The comparatively weaker effects of CE Innovation and CE Products & Services on CE Performance are expected theoretically rather than randomly. Both constructs represent downstream implementation outcomes influenced by multiple contextual factors (e.g., market conditions, operational constraints, regulatory environments). As a result, their effect sizes are naturally smaller than those of upstream CE Capability, which function as foundational enablers. This pattern aligns with the conceptual logic outlined in Section 5.3: capabilities exert their strongest influence on proximal, capability-driven outcomes (innovation and product–service development), whereas their impact on performance becomes progressively diluted as more context-dependent mechanisms come into play. The observed results therefore reflect a coherent, theory-driven causal structure rather than random associations.
Although mediation was not specified nor formally tested in this CE, the pattern of significant structural relationships suggests that the influence of CE Capability on CE Performance may be partially due to their effects on CE Innovation and CE Products & Services. This interpretation is consistent with (dynamic) capability-based reasoning, which suggests that organizational capabilities contribute to performance primarily by enabling innovation and the development of circular offerings rather than direct resource effects (Kristoffersen et al., 2021; Teece, 2007).

Consistent with the CE design and theoretical scope outlined in Section 5.3, no formal mediation analysis was conducted; these observations are therefore interpreted as theoretically meaningful patterns rather than statistically validated indirect effects.

To assess the model's predictive accuracy, the PLSpredict algorithm was applied with 10 folds and 10 repetitions, as recommended by Shmueli et al. (2019). The Cross-Validated Predictive Ability Test (CVPAT) was used to compare the model's predictive performance against a conservative linear model (LM) benchmark for all three target constructs: CE Products & Services, CE Innovation, and CE Performance. The results, summarized in Table 31, show that the PLS-SEM model achieves significantly lower prediction error than the LM benchmark for CE Performance (negative loss difference; $p < 0.01$), while predictive performance for CE Products & Services and CE Innovation is statistically comparable to the LM benchmark (non-significant differences).

Table 31: CVPAT Results

	PLS loss	LM loss	Average loss difference	*t* value	*p* value
CE Innovation	1.894	1.888	0.006	0.116	p = 0.907
CE Products & Services	1.475	1.466	0.009	0.265	p = 0.791
CE Performance	1.793	1.908	-0.115	4.376	p < 0.01

5.6 Discussion

5.6.1 Interpretation of the Findings

This study provides an integrated and empirically grounded capability system that complements prior research, which has often examined specific circular capabilities in isolation, such as CE innovation or implementation capabilities (Saari et al., 2024), or focused on capabilities related to circular business model development without integrating them into a higher-order system (de Arroyabe et al., 2021). By conceptualizing CE Capability as a multidimensional higher-order construct and empirically validating its effects, the findings deepen theoretical understanding of how bundles of interdependent capabilities jointly shape circular transitions. This addresses a well-documented gap in prior research, highlighting the need for system-level, large-sample evidence of how complementary capabilities collectively contribute to CE Performance outcomes (Govindan & Hasanagic, 2018; Pigosso & McAloone, 2021). Using PLS-SEM, the study examined the empirical relationships between CE Capability, encompassing several organizational capabilities, CE Innovation, CE Products & Services, and CE Performance.

The results show that CE Capability is a crucial determinant of CE Performance and affects outcomes primarily through its impacts on CE Innovation and CE Products & Services. These findings demonstrate that complementary capabilities operate collectively to drive circular outcomes, and do not act as isolated strategic or operational components.

The pattern of significant relationships among the constructs supports the conceptual model developed in Section 5.3. It confirms that capability-based mechanisms explain a substantial share of the variance in CE Performance through their combined effects on innovation and circular product–service development. This shows that organizational capabilities do not only translate directly into performance outcomes; they also operate through learning, experimentation, and resource reconfiguration processes that stimulate innovation and product and service redesign, which are key tenets of dynamic capabilities theory (Kristoffersen et al., 2021; Teece, 2007). Although no formal mediation analysis was conducted, the observed pattern is consistent with a mechanism-based interpretation in which CE Innovation and CE Products & Services act as intermediate pathways.

Capabilities as Drivers of CE Performance

The empirical results demonstrate that CE Capability, conceptualized as a multidimensional higher-order construct, constitutes a significant and substantive driver of CE Performance. The strong direct effect of CE Capability on CE Performance indicates that firms with more developed and mutually reinforcing capability dimensions achieve higher levels of CE Performance. While this direct effect represents only one component of the model's overall explanatory power, it constitutes a meaningful contribution further complemented by indirect effects operating through CE Innovation and CE Products & Services.

This finding underscores that superior circular outcomes do not stem from individual capabilities in isolation but from the integrated configuration of complementary capability dimensions within the higher-order construct. These results support the notion that CE Performance is associated with the integrated deployment of complementary capabilities rather than isolated capability dimensions. While the model does not directly compare individual versus integrated effects, the significant impact of the higher-order construct suggests that configuration and alignment play a central role in circular outcomes. This pattern is consistent with prior research suggesting that the alignment and coordination of complementary organizational capabilities are critical for explaining performance differences in circular transitions (Acquier et al., 2024; Kristoffersen et al., 2021; Teece, 2007).

Mechanisms underlying the effects of CE Capabilities

The results provide clear empirical evidence for the mechanisms through which CE Capability influences CE Performance. Rather than exerting a purely direct effect, CE Capability operates through two complementary pathways: CE Innovation and CE Products & Services. CE Capability strongly enhances CE Innovation, which in turn improves CE Performance and reinforces CE Products & Services. In parallel, CE Capability directly strengthens CE Products & Services, subsequently contributing to CE Performance. Collectively, these findings show that CE Capability influences performance through a cascading mechanism whereby capabilities stimulate innovation and product–service circularity, which then translate into measurable circular outcomes.

These patterns reinforce the conceptual model's central proposition: organizational capabilities affect circular outcomes primarily through learning, experimentation, and reconfiguration processes that enable innovation and product and service redesign. In line with dynamic capabilities theory, this highlights that capability deployment is mechanism-based, operating through adaptive and integrative routines rather than exerting uniform direct effects (Teece, 2007).

A plausible explanation for the endogeneity pattern observed in Section 5.5 is that the relationship between CE Capability and CE Products & Services is particularly susceptible to reciprocal reinforcement effects. Firms that already offer advanced circular products and services can further strengthen their internal capabilities through mechanisms such as experiential learning, customer feedback, or compliance with circularity-oriented regulations. Such mutual reinforcement makes this pathway more prone to endogeneity than the other structural relationships. For those relationships, reverse causality is substantially less plausible: CE Performance cannot create upstream capabilities, and innovation outcomes cannot precede the capability base from where they emerge. This theoretical interpretation aligns with prior research suggesting that capability development and circular offering development may co-evolve during circular transitions, as firms iteratively build capabilities through experiential learning and feedback from circular practices (Marrucci et al., 2022; Teece, 2007; Zollo & Winter, 2002).

Together, the results empirically substantiate the central proposition in this research: circular advantage emerges from the orchestration of interdependent capabilities that jointly enable innovation and product–service circularity. By linking these empirical patterns to the conceptual rationale developed in Section 5.2, the findings reinforce the view that circular transitions are systemic, capability-based processes rather than isolated initiatives.

5.6.2 Theoretical Implications

This research refines the theoretical understanding of how organizational capabilities generate CE Performance by empirically contextualizing RBV within circular transition settings. Rather than expanding the theoretical boundaries of RBV, this research clarifies why its mechanisms are manifest in CE settings that prior literature characterizes as complex, interdependent, and system-wide (Bocken et al., 2016; Geissdoerfer et al., 2017; Kirchherr et al., 2017). It demonstrates that CE Performance emerges not from resource possession alone, but from the orchestration of interdependent organizational capabilities that enable CE Innovation and the development of CE Products & Services.

By conceptualizing and empirically validating CE Capability as a higher-order construct, composed of interdependent capability dimensions, our research advances the capability-based understanding of circular transitions. This multidimensional conceptualization integrates interdependent capabilities into a coherent theoretical framework, offering empirical insight into how resource-based mechanisms operate in CE contexts.

Building on this foundation, the findings move the discussion beyond isolated drivers of circular transition by clarifying how core RBV mechanisms, together with their extensions in dynamic capabilities theory and the natural RBV, operate in CE contexts, demonstrating that CE Performance arises from the coordinated deployment of interdependent organizational capabilities, not isolated resource advantages (Hart, 1995; Teece et al., 1997).

While dynamic capabilities theory emphasizes a firm's ability to sense, seize, and reconfigure resources, and the natural RBV focuses on environmentally valuable competences, this research demonstrates empirically that CE Performance depends on their integrated operation within a higher-order capability system. Dynamic mechanisms, such as learning, innovation, and integration, appear to translate circularity-oriented resources into circular outcomes when operating alongside broader relational and resource-oriented capabilities. Rather than offering a full empirical test of dynamic or natural RBV, the findings clarify how key mechanisms from these perspectives operate in CE contexts by showing that they are embodied in an integrated, higher-order CE Capability construct that combines resource-based, dynamic, and relational dimensions.

This research also contributes to the theoretical evolution of RBV by addressing its firm-centric limitations. Traditional RBV assumes that competitive advantage arises primarily from firm-specific assets, whereas circular transitions increasingly rely on inter-organizational collaboration and ecosystem-level orchestration (Adner, 2017; Dyer & Singh, 1998; Jacobides et al., 2018). By empirically capturing cross-functional and integrative mechanisms, this research clarifies how core RBV assumptions materialize within complex and collaborative circular settings. Instead of extending the RBV, the findings refine its explanatory scope by showing that resource-based mechanisms in CE contexts depend on coordinated, relational, and system-level capabilities.

Recent conceptual advances support this view: Acquier et al. (2024) show that scaling CBMs requires capability integration across organizational and institutional layers, while Kanda et al. (2025) define ecosystem orchestration as a meta-dynamic capability that aligns collaboration, learning, and institutional support.

5.6.3 Practical Implications

The following paragraphs outline the practical implications at different organizational and institutional levels.

Managerial Implications. From a managerial perspective, the findings translate into three actionable priorities: (1) strengthen internal learning and collaboration capabilities, (2) invest in circular innovation and product–service systems, and (3) embed governance structures that support consistent circular practices. These priorities are directly derived from the significant relationships identified in the structural model, ensuring that they are grounded in empirical evidence and not purely normative guidance.

The results highlight that developing CE Capability, particularly through innovation-oriented and integrative capability dimensions such as collaboration, is as a key enabler of CE Performance. Innovation-oriented capabilities drive the redesign of products, services, and business models, enabling resource efficiency and extending product lifecycles. Firms can support this process by strengthening the organizational conditions that enable circular innovation, such as improving information flows, enhancing collaboration between technical and commercial functions, and creating flexibility in design and development routines. To sustain such innovation, firms should foster internal learning mechanisms and cross-functional collaboration, as internal capability integration often precedes successful external partnerships (Bressanelli et al., 2019; Nujen et al., 2023). This underscores that effective circular implementation depends on coordinated inter-firm efforts supported by technological enablers and shared objectives.

Marketing and Communication Capability also plays a pivotal role by translating technical progress into organizational commitment and market acceptance. Effective communication of the economic and environmental benefits of circular products strengthens stakeholder engagement and customer adoption (Bocken et al., 2016; Kazancoglu et al., 2018).

Managers should therefore ensure that circular innovation initiatives are embedded in existing organizational routines and communication practices, so that innovation efforts are consistently supported and translated into both environmental and economic benefits.

Policy and Ecosystem Implications

Beyond firm-level managerial action, the findings are also relevant for policymakers, industry associations, and other ecosystem actors. Regulatory frameworks and incentive structures can accelerate organizational investment in circular capabilities by aligning corporate practices with standardized benchmarks (Geissdoerfer et al., 2018; Kirchherr et al., 2017). Public–private collaboration is critical to build innovation ecosystems that facilitate knowledge sharing, joint experimentation, and the diffusion of CBMs (Acquier et al., 2024; Kanda et al., 2025).

While ESG alignment and compliance were not directly measured in this study, the findings provide a conceptual basis for understanding how the development of CE Capability may support firms in navigating emerging governance expectations. Specifically, integrative and learning-oriented capabilities can enhance firms' ability to generate, coordinate, and communicate reliable circularity-related information across functions and partners, which are prerequisites for transparency, consistency, and accountability in sus-tainability reporting. Rather than asserting a direct empirical link, these implications indicate where capability development may interact with governance requirements under frameworks such as the EU CE Action Plan (European Commission, 2020a).

Based on recent research into governance mechanisms for circular transition, we argue that transparent circularity disclosure and adaptive governance structures can support the development of circular capabilities (Babkin et al., 2023; Chen & Xie, 2022; Zhang et al., 2024), whereas overly rigid controls may hinder organizational learning and in-novation (Carnini Pulino et al., 2022). Effective policy design should therefore balance accountability with flexibility, enabling firms to innovate while ensuring transparency and comparability in sustainability reporting. This resonates with the systemic governance–CE integration perspectives proposed by Agyemang et al. (2025) and Kopnina et al. (2025).

Capability Development Pathways

Based on the structure of the empirically validated higher-order CE Capability construct and the significant relationships observed in the structural model, our findings can be translated into three practical capability development pathways:

1. **Foundation:** Strengthen internal learning, monitoring, and leadership capabilities to create strategic alignment and a shared sense of purpose.
2. **Integration:** Leverage collaboration and operational capabilities to embed circularity across business functions and supply chains.
3. **Innovation:** Use innovation and marketing capabilities to scale circular products, services, and business models, transitioning circular intent into measurable outcomes.

These pathways reflect clusters of interrelated capabilities that jointly shape the in-direct pathways from CE Capability to CE Performance via CE Innovation and CE Products & Services. The pathways should not be interpreted as sequential stages but as complementary areas of capability development that firms can prioritize based on their context and strategic needs. Together, these pathways serve as a diagnostic lens that helps firms assess which capability dimensions underpin their CE performance. They complement the CMT by clarifying how different capability dimensions contribute to circular transition outcomes, without implying predefined maturity stages or a fixed sequence of development.

By systematically strengthening these capability dimensions, firms can improve their readiness for market-driven and regulatory transitions to a CE, as these capabilities improve organizational learning, coordination, and integration processes that enable firms to respond more effectively to changing market demands and governance requirements. Although this discussion links capability development to governance expectations, ESG alignment and regulatory compliance were not empirically tested in the model. Future research should therefore validate these connections through extended measurement of ESG- and policy-related constructs, ensuring that capability-based pathways to CE Performance are fully captured.

5.6.4 Limitations and Future Research

Despite the valuable insights this research provides regarding the role of circular capabilities in shaping CE Performance, several limitations must be acknowledged. These limitations also highlight promising directions for future research that can deepen theoretical understanding and strengthen empirical generalizability.

Methodological Limitations

First, the cross-sectional nature of this study limits insights into how circular capabilities develop over time and affect performance in the long run. Future research should therefore use longitudinal studies to examine how changes in these capabilities shape circular outcomes. Longitudinal studies could also build on recent conceptual work that distinguishes between ordinary and dynamic circular capabilities (Lombani et al., 2025).

Future research could examine whether such capability types can be empirically distinguished in circular transitions and how they evolve or interact over time within firms.

Second, the mixed sampling strategy, combining purposive targeting of firms active in CE initiatives with an open-access online survey, may have introduced a degree of self-selection bias. Firms already engaged in circular practices were more likely to participate, potentially overrepresenting more mature firms. However, this approach was intentionally chosen to ensure adequate heterogeneity across industries and firm sizes. Future studies should apply stratified or random sampling across different maturity levels to enhance external validity and generalizability. In addition, 47 organizations provided multiple responses originating from different business units within the same firm, introducing a degree of intra-firm clustering. While these responses offer insight into intra-organizational variation in CE practices, such clustering may bias standard errors. Although PLS-SEM is relatively robust to this form of heterogeneity (Hair et al., 2021), future research could explicitly assess clustering effects, for example by estimating models at the firm level or applying multilevel approaches.

Third, although procedural and statistical controls were applied to mitigate CMB, the use of a single-informant design may still incur shared method variance. Future research could combine survey data with objective performance indicators, such as ESG scores or environmental efficiency metrics, to validate the observed relationships and reduce per-ceptual bias (Kock, 2015; Podsakoff et al., 2003). Integrating perceptual and archival measures e.g., from the London Stock Exchange Group (LSEG) Refinitiv database, Sustainalytics, or the Carbon Disclosure Project (CDP) would further strengthen empirical robustness.

Contextual and Boundary Limitations

The findings are shaped by contextual factors that may limit external generalizability. All respondents were based in the Netherlands, a context characterized by advanced circular policies and circular awareness. While this homogeneity enhances internal validity, it may constrain applicability to other institutional environments, including different policy frameworks. Future studies could replicate the analysis in international and cross-sectoral settings to assess whether the relationships between capabilities and performance hold across such contexts.

Moreover, sectoral characteristics, such as regulatory pressure and resource intensity, may influence the strength and direction of capability–performance relationships. Comparative, industry-specific studies could reveal how sectoral dynamics and supply chain structures shape the effectiveness of circular capabilities.

External variables such as regulation, cultural norms, and market conditions also warrant explicit inclusion as moderators or control factors in future models to test their contextual influence on capability deployment.

Theoretical and Model-Related Limitations

While this research applies RBV to the CE context, it does not seek to extend the theory's conceptual boundaries. Instead, it operationalizes RBV's capability-oriented constructs for CE-driven transitions, without directly measuring underlying resource stocks. Future studies could theorize more explicitly how circular-specific and relational resources reshape traditional RBV assumptions and whether these resources exhibit VRIN characteristics, confirming their potential for sustained advantage.

The current model intentionally prioritized theoretical parsimony by focusing on capability relationships rather than incorporating explicit control variables. This choice enabled a clear test of the core capability–innovation–performance structure, but it also implies that potentially relevant contextual and organizational factors remain in the error term and should be incorporated more explicitly in future research.

Unexplored Mechanisms and Boundary Conditions

Beyond the limitations discussed above, the results point to several unexamined mechanisms and boundary conditions that warrant further investigation.

The relatively weaker downstream paths from CE Innovation and CE Products & Services to CE Performance indicate that the translation of innovation into performance may depend on contextual conditions. Prior research suggests that factors such as ecosystem maturity, inter-organizational coordination, and institutional alignment shape whether innovation outcomes can be scaled effectively (Acquier et al., 2024; Kanda et al., 2025). While such contingencies were not measured in this research, they offer plausible explanations for variation in effect strength and represent promising avenues for future research.

Beyond these contextual considerations, earlier studies propose that the effectiveness of circular capabilities may be influenced by organizational characteristics such as absorptive capacity or resource slack (Levinthal & March, 1993; Lombani et al., 2025; Zollo & Winter, 2002). These factors were not included in the empirical model and therefore cannot be assessed here, but they point to theoretically grounded boundary conditions that may shape capability effectiveness and warrant further investigation.

The analysis further revealed indications of non-linear relationships in the structural model, suggesting that the strength of CE capability effects varies across capability levels.

This aligns with dynamic capabilities theory, which argues that learning and reconfiguration processes may produce accelerating or diminishing returns depending on a firm's adaptability (Teece, 2007). Although this research does not test specific mechanisms such as capability traps, the observed non-linearities indicate that capability accumulation may not yield uniform performance gains across contexts. These patterns merit further examination in future research.

5.7 Conclusions

This research examined the organizational capabilities that influence CE Performance, offering empirical insights into how CE Capability drives both CE Innovation and the development of CE Products & Services. The findings highlight the value of a structured capability approach in supporting firms' CE Performance.

Across the structural relationships, the strongest empirical effect we observed was the influence of CE capability on CE Innovation, followed by its effect on CE Products & Services and its moderate direct effect on CE Performance. The downstream effects of CE Innovation and CE Products & Services on CE Performance were positive yet comparatively weaker. This pattern reinforces the conclusion that CE Performance is shaped primarily through capability-enabled innovation and product–service development, not direct capability effects alone.

By connecting CE Capability development with RBV logic, our research demonstrates the empirical applicability of this theoretical foundation to circular transition contexts and shows how capabilities, if effectively deployed, translate into measurable performance outcomes. As firms face mounting pressure to integrate ESG considerations into their strategies, the development of robust circular capabilities becomes increasingly important for achieving measurable CE Performance improvements and supporting the broader transition to sustainable business practices.

This research contributes by identifying the pathways for capabilities to drive circular outcomes, thereby informing both theoretical understanding and practical application. Future research and policy efforts can build on these insights by examining how circular capabilities evolve across maturity levels and under varying regulatory or institutional conditions. Addressing these issues through longitudinal, cross-sectoral, and multi-level research will be crucial for explaining how firms bundle and reconfigure capabilities to scale CBMs across institutional environments. Integrating theoretical refinement with empirical expansion will thus deepen our understanding of capability evolution as a driver of systemic circular transition.

CHAPTER

6

Discussion and Conclusions

6. Discussion and Conclusions

Advancing the transition to a Circular Economy (CE) requires not only measuring performance, but also understanding how firms develop the capabilities needed to progress along their circular maturity path. This research addressed that challenge by integrating indicator- and maturity-based approaches into a multi-dimensional maturity framework. This final chapter summarizes the core of the research, presents the key takeaways, discusses implications for theory and practice, and ends with reflections on limitations and future research directions.

This dissertation can be understood as a coherent Design Science (DS) research trajectory aimed at the systematic development and validation of the Circular Maturity Tool (CMT). Though the individual phases are presented in separate chapters, collectively they represent an integrated and iterative research process. In particular, chapters 2–4 form the core of the DS cycle, moving from the conceptualization of the research design (Chapter 2), through the development of the initial artifact (Chapter 3), to its iterative evaluation and refinement via alpha and beta testing (Chapter 4). Chapter 5 extends this core cycle by providing large-scale empirical insights into the relationship between circular capabilities and CE Performance outcomes, thereby strengthening the empirical grounding and external validity of the developed artifact.

6.1 Synopsis

This research addresses firm-level CE research by integrating two approaches: indicator-based methods that emphasize measurement and benchmarking (Bocken et al., 2025; de Arroyabe et al., 2021; Kristensen & Mosgaard, 2020; Kuzma et al., 2021; Vinante et al., 2021) and Maturity Models (MMs) that focus on developmental progression and readiness assessment (Julkovski et al., 2023; Kayikci et al., 2022; Pigosso & McAloone, 2021; Sacco et al., 2021; Sehnem et al., 2020; Uhrenholt et al., 2022). Both streams, while insightful, suffer from conceptual fragmentation (conceptual coherence, human factors, dynamic view, theoretical integration) and methodological limitations (integration & validation, empirical grounding, practical usability, large-scale validation, theory-grounded validation).

To address these shortcomings and advance the research field, this study adopted a systems thinking perspective and a DS methodology.

The study's main objective was to design, integrate, and validate a MM that supports firms in assessing and developing their capabilities to advance circular maturity. This objective was achieved through the development and validation of the CMT, a capability-based MM. The CMT integrates indicator and MM approaches by linking operational metrics with development logic. Its comprehensive validation followed an iterative multi-phase process, including conceptual design, empirical refinement, and large-scale validation using PLS-SEM, based on the Resource-Based View (RBV) and dynamic capabilities theory. The CMT supports both diagnostic assessment and strategic development, stimulates internal dialogue and learning, and offers a conceptual lens to understand capability development within broader systemic transitions. By achieving this objective, the study answers the research question formulated in Chapter 2 and, in doing so, addresses the conceptual and methodological gaps identified in Chapter 1.

Developing the CMT by combining the two research approaches resulted in the identification of ten dimensions that determine circular maturity at the firm level: Strategy, Business Model, Environmental Impact Data, Leadership & Culture, Skills, Communication, Innovation & Technology, Internal Operations, Products & Services, and Value Chain Collaboration. Each of these dimensions comprises several capabilities, adding up to a total of 76 capabilities (listed in Appendix K). Validation across the full DS cycle included 491 survey respondents and 95 interviews involving 58 firms. This comprehensive validation not only confirmed the CMT's ability to systemically assess circular maturity at the firm level, but also demonstrated that the ten dimensions are interdependent and together reflect a learning-oriented maturity structure.

The study demonstrates that advancing circular maturity requires an integrated perspective that links capability development and performance measurement within a systemic and dynamic framework. In doing so, the research objectives formulated in Chapter 1 are addressed by (1) integrating fragmented conceptual elements into a coherent maturity framework, (2) validating this CMT through iterative and empirical methods, and (3) demonstrating how organizational capabilities relate to CE Performance.

6.2 The Dissertation's Contributions

While this study's contributions are discussed throughout the individual chapters, they are consolidated here to provide a coherent overview and clarify how the dissertation addresses the research gaps identified in Chapter 1. More specifically, the contributions reported below show how this dissertation responds to the conceptual gap, concerning the fragmented treatment of dimensions, indicators, maturity stages, and capabilities.

And, in addition to the methodological gap, concerning the limited use of theory-grounded, iterative, and empirically robust validation approaches in existing circular maturity research. Based on the DS trajectory and the empirical findings in Chapters 3–5, we have grouped the contributions under the headings theoretical, methodological, and practical (see Table 32).

Table 32: This Dissertation's Main Contributions

Type	Contribution	Chapters
Theoretical	Integration of indicator-based and maturity-based approaches into a unified capabilitybased CMT for circular maturity	1, 3, 4, 6
Theoretical	Reconceptualization of circular maturity as a dynamic, capability-based and coevolutionary process rather than a static stage model	1, 5, 6
Theoretical	Empirical substantiation of the relationship between circular capabilities and CE Performance	5
Methodological	Demonstration of a full DS cycle integrating artifact development, iterative evaluation (alpha/beta), and large-scale validation	2, 3, 4, 5
Methodological	Application of the Design Science Validity Framework (DSVF) combining criteria, context, and causal validation	4, 5
Practical	Development and validation of the CMT as a usable and scalable assessment instrument	3, 4, 5
Practical	Provision of a tool supporting firms in diagnosing, benchmarking, and developing circular capabilities	4,5,6

The theoretical contributions address the conceptual gap by integrating indicator-based and maturity-based approaches in a coherent capability-based understanding of circular maturity. The methodological contributions address the methodological gap by demonstrating how artifact development, iterative evaluation, and empirical validation can be combined in a theory-grounded DS process. The practical contributions show how these conceptual and methodological advances result in a usable and scalable assessment instrument for firms. In this way, the findings in Chapters 3–5 are explicitly aligned with the dissertation's objectives and overall contribution to circular maturity research. More specifically, the alignment between research gaps, objectives, and findings can be traced across the individual chapters. The conceptual gap is primarily addressed in Chapters 3 and 4, where existing indicator-based and maturity-based approaches are systematically integrated into a coherent capability-based framework, resulting in the ten-dimensional structure of the CMT. The methodological gap is addressed through the full DS cycle.

Chapter 4 contributes by iteratively evaluating and refining the artifact through alpha and beta testing in real-world contexts, thereby strengthening practical usability and context validity. Chapter 5 further addresses this gap by empirically validating the relationship between circular capabilities and CE Performance with PLS-SEM, providing large-scale and theory-grounded evidence.

6.3 Implications

Building on DS principles and their alignment with the DSVF, this research demonstrates how systematic construct development can be combined with large-scale validation. Specifically, iterative artifact design is integrated within the alpha, beta, and causal validation phases. While the alpha and beta stages establish criterion and context validity for the capabilities- and performance-related constructs, subsequent large-sample testing using PLS-SEM indicates causal validity. This approach illustrates how DS principles can support theory-guided construct adaptation in emerging fields such as circular economy research, thereby helping to bridge the rigor–relevance gap.

The developed and validated CMT and the established relationships between CE Capability and CE Performance contribute to both academic knowledge and practical problem-solving in organizational contexts (Hevner et al., 2004). Rather than treating methodological contributions separately, the DS approach is embedded in the theoretical and practical contributions. Theoretically, it supports the development and validation of a systemic, capability-based understanding of firm-level circular maturity. Practically, it supports the iterative development, improvement, and application of the CMT in real-world settings. Together, these contributions advance both scholarly insight and managerial relevance, and are discussed in the following sub-sections.

6.3.1 Theoretical Implications

Figure 2 and Table 2, in Chapter 1, visualize the dual lineage of CE Performance measurement approaches, separating indicator-based frameworks focused on performance measurement from CE MMs that emphasize staged organizational development. This research is based on the recognition that these two approaches, though complementary, have often evolved in parallel with limited integration, resulting in fragmented insights and limited support for firms navigating the circular transition. From a practical and theoretical perspective, both approaches fall short when applied in isolation. Indicator frameworks provide detailed performance metrics, but often lack developmental logic to guide learning and progression (Bocken et al., 2025; de Arroyabe et al., 2021; Kristensen & Mosgaard, 2020; Kuzma et al., 2021; Vinante et al., 2021).

In contrast, MMs emphasize the development of organizational capabilities, but often operate at a high level of abstraction, lacking empirical grounding and clear links to operational results (Julkovski et al., 2023; Kayikci et al., 2022; Pigosso & McAloone, 2021; Sacco et al., 2021; Sehnem et al., 2020; Uhrenholt et al., 2022). Due to the increasing demands on firms to both measure and mature their CE efforts, a more integrated evaluative logic is required.

Against this backdrop, this research combined the indicator-based and maturity-based approaches into a single systemic CMT. The resulting CMT links operational indicators with capability-based maturity dimensions, thereby aligning performance assessment with capability development. This integration responds directly to the need for conceptual coherence, clarifying how performance metrics relate to underlying organizational capabilities and how firms can use this insight to guide targeted capability-building. Without such alignment, firms risk remaining trapped in either diagnostic exercises with limited developmental guidance, or conceptual models lacking empirical grounding, hindering both strategic learning and implementation.

Although conceptual coherence was the initial rationale for integration, the synthesis also revealed broader theoretical and methodological limitations in the field. As shown in Table 2, these include four conceptual factors (conceptual coherence, human factors, dynamic view, theoretical integration) and five methodological factors (integration & validation, empirical grounding, practical usability, large-scale validation, theory-grounded validation). These factors undermine the robustness of existing models. Consequently, current approaches often fall short in both explaining and supporting firm-level circular transitions.

To address these limitations, this research applied a DS approach grounded in a systemic perspective. Systems thinking provides the theoretical lens to conceptualize CE capability development as a co-evolving multi-dimensional process shaped by feedback loops across practices, resources, and outcomes. For instance, the model suggests that the integration of circular design practices may lead to learning effects that influence resource allocation decisions in subsequent innovation cycles, a dynamic that is typically under-represented in linear capability models. DS complements this by offering a structured and iterative methodology to design and evaluate the CMT as a theoretically informed artifact. Together, systems thinking and DS enable the identification and resolution of the nine conceptual and methodological factors that emerged from combining the indicator and MM approaches.

Conceptual coherence was strengthened by aligning metrics with developmental logic; human factors were embedded through qualitative insights gathered during artifact testing; the dynamic view factor was addressed by emphasizing iterative feedback loops; and theoretical integration was achieved by linking resource-based and capability-based views in one systemic CMT. Methodologically, the DS approach allowed repeated development and improvement of the CMT through real-world application, ensuring both rigor and relevance. Each DS cycle contributed empirical grounding to conceptual insights, transforming abstract gaps into actionable, theory-informed features of the CMT. Building on this foundation, three key theoretical implications emerge.

First, this research redefines the understanding of circular maturity from static, assessment-oriented frameworks to dynamic, capability-based explanations of organizational change.

Existing CE MMs predominantly adopt a stage-based view, focusing on what firms should achieve rather than how they evolve (Julkovski et al., 2023; Kristensen & Mosgaard, 2020; Pigosso & McAloone, 2021; Vinante et al., 2021). This limits the ability to explain the underlying dynamics of learning, adaptation, and transition. In contrast, this research adopted a dynamic capability-based perspective, offering a theoretical foundation by examining how firms may sense opportunities, reconfigure resources, and adapt to shifting environmental and institutional conditions. This shift advances theoretical understanding in two exemplary ways. It contributes to cumulative theorizing by grounding model development in iterative empirical cycles, thus progressively building theory that is both rigorous and contextually relevant (Post et al., 2020). Additionally, it draws on sensemaking theory to illustrate how firms in-terpret complexity, respond to ambiguity, and construct meaning throughout their CE journey (Weick, 1995). Together, these perspectives help move beyond descriptive stage models towards an explanation of how firms learn, adapt, and co-shape broader system transitions.

Second, this research contributes new conceptual insights into how circular capabilities co-evolve with external systems over time. Although the literature has long acknowledged that change at the firm and system level is interdependent (Greenwood et al., 2002; Maes & Van Hootegem, 2019; Smith et al., 2010), this study offers empirical evidence of how this interdependence operates in practice. In all empirical phases, interviews, surveys, and Delphi rounds, participants emphasized the role of the external context in shaping internal CE development. The findings show that regulatory signals prompt strategic realignment and compliance-driven innovation; network collaboration facilitates knowledge exchange and peer learning; and evolving market expectations encourage firms to develop customer-oriented circular solutions.

At the same time, firms influence broader system dynamics, creating a recursive relationship. For example, several firms noted that upcoming EU CE directives prompted them to initiate cross-departmental innovation projects, aimed at aligning product design and logistics with circular requirements. These insights underscore that circular transition is not only multilevel but also co-evolutionary. They highlight the dynamic nature of CE capability development and suggest that firm-level learning can only be fully understood in interaction with wider systemic influences.

Building on this empirical foundation, the third contribution lies in advancing the theoretical framing of circular maturity. By adopting a systemic lens, this research broadens the conceptualization of circular maturity by emphasizing its embeddedness within broader industrial and institutional contexts. Although the analytical focus re-mains at the firm level, the findings reveal how external structures, such as regulatory environments, industry norms, and value chain relationships, influence internal capability development. This opens pathways for connecting circular maturity research with adjacent theoretical domains, including institutional theory, socio-technical transitions, and sustainable entrepreneurship (Bocken et al., 2014; Delmas et al., 2019).

This research offers a theoretical reframing of circular maturity. Rather than viewing maturity as a linear progression through discrete stages, it is conceptualized as a systemically embedded and co-evolving process. This challenges the dominant logic in much of the circular maturity literature, which tends to emphasize static stage models over dynamic interaction. In contrast, the systemic perspective introduced here highlights how internal capabilities and external system conditions interact recursively over time, shaping firm-level development as part of a broader, adaptive transformation journey. These similarities and differences position the CMT not as a replacement of prior circular maturity approaches, but as an integrative extension that bridges indicator-based and maturity-based traditions within a capability-based and empirically validated design.

6.3.2 Practical Implications

Alongside its theoretical implications, this research provides significant value to practitioners seeking to advance circular transitions. Based on a practice-based research perspective, this research aligns with the PRIME (Practice-based Research Impact Model for Evaluation) framework, which distinguishes four impact pathways: knowledge development, product development, personal development, and system development (Greven & Andriessen, 2019). PRIME emphasizes non-linear, iterative impact creation during and after the research process. While knowledge development is addressed through the theoretical implications outlined in the preceding section, the remaining three pathways form the basis for the reflection on the practical implications.

At product level, the research delivered a validated framework: the CMT. Developed through iterative co-creation and embedded in real organizational contexts, the CMT offers firms a structured yet adaptable approach to assess their circular maturity and identify priority areas for development. Its modular architecture and empirical foundation have enabled its application across sectors and organizational types, from Small and Medium Enterprises (SMEs) to governmental bodies and large enterprises. During and after the research, the CMT is used not only for assessment purposes but also as an intervention instrument in strategy sessions, learning environments, and change programs. It has catalyzed the development of related formats for benchmarking, education, and regional policy-making. In education, dedicated funding from TKI-Dinalog supports the development of modular learning programs by four Dutch universities of applied sciences, directly aligned with CMT dimensions and integrated into a CMT platform. For benchmarking, an automated results environment now provides survey respondents with immediate comparative feedback based on embedded benchmark datasets in Qualtrics.

At policy level, the launch of the first report *Staat van Circulair Ondernemen* in March 2025 used CMT data to inform regional policy development on circular entrepreneurship (Pape et al., 2025). Building on this, a second edition released in early 2026, further leveraged CMT data to support ongoing policy development and public–private dialogue, including its formal presentation to Queen Máxima of the Netherlands. Additionally, CMT was compared with the biennial ICER report by PBL (PBL Netherlands Environmental Assessment Agency, 2025), linking firm-level self-reported maturity CMT data with macro/meso-level system metrics from the MIS database (Elzinga et al., 2020; Elzinga et al., 2023).

On the personal development level, the research involved a wide range of stakeholders, such as researchers, firm representatives, policy advisors, educators, and students, who actively contributed to and learned from the design and validation processes. Their participation supported the development of skills related to systems thinking, circular reasoning, and strategic foresight. Interviewees frequently reported a shift in mindset: from viewing circularity as a regulatory obligation to seeing it as a strategic opportunity. Extensive dissemination through presentations, masterclasses, workshops, and open-access materials (as listed in detail in Appendix C) extended this impact well beyond the immediate research community.
At system level, CMT facilitates institutional change by serving as a boundary object that enables shared understanding and coordinated action across diverse stakeholder groups. In DS, such boundary objects play a critical role in bridging the gap between scientific knowledge and practical application by maintaining both interpretive flexibility and structural coherence (Gauss et al., 2024).

In practice, its application has for example led firms to revise procurement criteria (e.g., integrating circularity in supplier selection), redefine performance indicators such as introducing Key Performance Indicators (KPIs) for circular innovation, and initiate new collaboration modes, for instance, setting up cross-departmental teams to address maturity gaps revealed by the CMT. The CMT supports strategic dialogues within firms and across ecosystems, such as regional CE programs and public-private consortia. For example, in a supply chain study involving high-tech Original Equipment Manufacturers (OEMs) and suppliers in the Eindhoven region, supported by the Province of Noord-Brabant, Brainport Eindhoven, and Brabant Development Agency (BOM), CMT facilitated shared assessment and dialogue. This process led to stronger collaboration across the value chain and supported circular capability development at both the firm and network level. With over 3,000 survey responses from more than 900 firms, the CMT has already demonstrated ecosystem-level reach and influence.

While further longitudinal research is needed to fully understand long-term transformation, initial outcomes point to the CMT's ability to structure and accelerate organizational learning and transition pathways, as illustrated by its application in national impact reporting and policy-oriented initiatives (see also Chapter 4). Through these multiple impact mechanisms, the CMT embodies the PRIME vision rather than a linear dissemination model. Indeed, this research embraces the non-linear, iterative nature of real-world transitions, resonating with PRIME's emphasis on knowledge creation, personal and system-level learning, and the design of actionable tools as a legitimate form of scientific impact (Greven & Andriessen, 2019; Ravesteijn, 2025).

6.4 Key Takeaways

This research yields several key insights into the development, validation, and application of the CMT in assessing a firm's CE Performance.

First, the CMT integrates indicator-based and MM-based research approaches. By linking performance metrics with capability-based dimensions, it demonstrates that measurement alone is not sufficient. A developmental logic is essential to support firms in learning, adapting, and progressing to higher levels of circular maturity.

Second, the findings highlight that circular maturity is inherently non-linear. Firms demonstrate differentiated progression across various dimensions, suggesting that circular transition follows multiple, context-specific trajectories rather than a uniform pathway.

Third, organizational factors emerged as crucial enablers of circular transition. Elements such as leadership commitment, organizational culture, and collaboration significantly influence how circular capabilities are developed and embedded. Although previous studies have acknowledged these factors, this research strengthens the empirical basis by showing how they concretely shape capability development in diverse organizational contexts.

Fourth, the theoretical underpinning of CMT, grounded in RBV and dynamic capabilities theory, enhances its explanatory strength. This theoretical integration enables a richer understanding of how firms sense, seize, and reconfigure resources in pursuit of circularity. For example, several participating firms used CMT insights to sense new regulatory and market signals around circularity, seize these opportunities by prioritizing circular product development, and reconfigure their R&D and procurement processes to align with circular design principles.

Fifth, this research demonstrates that scientific rigor and stakeholder relevance can be successfully combined for developing MMs. By applying DSVF at all stages and involving practitioners through co-design and iterative feedback, CMT achieved both methodological robustness and practical usability, a combination often considered difficult to achieve in transdisciplinary research (Lang et al., 2012).

Finally, the iterative design and empirical validation of the CMT, guided by the DSVF, ensures that the CMT is both scientifically rigorous and practically usable. This dual emphasis supports its adoption in both academic and organizational contexts.

6.5 Limitations and Future Research

6.5.1 Limitations

While this research provides meaningful theoretical and practical implications for the understanding and assessment of circular maturity at the firm level, it is important to reflect on several limitations that frame the scope and applicability of its findings.

First, the geographic focus of the research was limited to the Netherlands. Although the Netherlands is often regarded as a frontrunner in CE policy and innovation (Circle Economy, 2023), this national context may not fully reflect the institutional, cultural, or regulatory environments of other regions. As such, the applicability of the developed CMT and associated findings to international contexts needs to be tested. Future research should explore cross-national or global validations to enhance the external validity of the CMT.

Second, although the research was initially designed to be industry-agnostic, the emphasis shifted towards the manufacturing sector. This shift occurred primarily due to the limited availability of robust CE literature for sectors outside the manufacturing domain. Consequently, certain dimensions, capabilities, and validation outcomes may be more reflective of manufacturing firms, potentially limiting applicability to service-based or knowledge-intensive industries.

Third, while the CMT was validated through an extensive empirical process, including expert interviews, surveys, and case studies, the sample consisted predominantly of Dutch firms, and many of them were already engaging actively in sustainability or CE initiatives. This was evident from interview responses, prior participation in CE-related programs, and self-reported maturity levels in the initial CMT assessments. This may introduce a selection bias, potentially limiting the generalizability of the findings to firms with lower awareness or engagement in CE practices.

Fourth, the research design, although rooted in rigorous DS principles, required certain methodological choices and trade-offs. The prioritization of breadth (capturing a wide set of dimensions and capabilities) may have come at the expense of depth in specific areas. Moreover, the reliance on self-reported data in surveys and interviews introduces the possibility of social desirability bias, which could affect the reliability of responses.

Fifth, although CMT recognizes the systemic embeddedness of circular transitions and has been adopted across organizational ecosystems, the empirical analyses in this research focused primarily on firm-level assessment. The research did not include an in-depth examination of inter-organizational or system-level mechanisms, such as supply chain governance, ecosystem dynamics, or policy interactions, which therefore fall outside its analytical scope.

Sixth, the CMT assigns equal weight to all maturity dimensions. While this design choice improves simplicity and interpretability, it does not account for potential differences in the relative importance of dimensions across firms, sectors, or maturity levels. In practice, dimensions such as innovation or value chain collaboration may exert a disproportionately larger influence on CE Performance. Future research could consider developing weighted models that reflect empirical priorities or sector-specific characteristics.
Finally, the actual CMT, as a designed artifact, represents the first generation of a measurement framework. Despite iterative testing and refinement, its long-term applicability, adaptability to sector-specific contexts, and integration with decision-support systems warrant further investigation.

By critically acknowledging these limitations, this research not only ensures transparency, but also highlights several promising avenues for future research. Such avenues are comparative cross-country validation, sector-specific adaptations, refined weighting schemes, longitudinal studies, analyses at the value chain level, and methodological enhancements to balance breadth and depth. These directions provide a solid foundation for strengthening, contextualizing, and expanding the work presented here. We end this chapter by describing complementary research spin-offs that extend beyond these limitation-driven directions.

6.5.2 Directions for Future Research

At present, the CMT is fully implemented in practice, with new data being collected daily. While the initial validation primarily involved Dutch firms, the CMT has since become a foundational tool for initiating circular transitions in a growing number of firms, both within and beyond the Netherlands. Several complementary initiatives have been launched or are in development, some of which were outlined in section 6.3.2 (Practical Implications). Building on these, future research could explore their broader impact, effectiveness, and scalability. These initiatives include the potential integration of the CMT with macro-level monitoring instruments such as the biennial ICER report by PBL (PBL Netherlands Environmental Assessment Agency, 2025), the development of sector-specific versions (e.g., construction and healthcare), and international collaborations focused on country-specific validation studies. In sum, along with the limitation-driven directions outlined above, this study gives rise to various research spin-offs.

A promising line of inquiry involves "best versus the rest" analysis using the dataset collected through CMT assessments. By examining performance patterns among firms with varying maturity levels, researchers may identify success factors that distinguish high performers in the circular transition from their peers.

The growing database of CMT assessments offers opportunities for benchmarking across sectors, geographies, and firm types. Such comparative studies could uncover trends, clustering patterns, and maturity trajectories, thereby providing valuable strategic insights for practitioners and policymakers alike.

Future research could further strengthen the CMT's prescriptive capacity by developing evidence-based recommendations for advancing each dimension. This may involve combining empirical data, literature insights, and firm-specific profiles to yield targeted intervention strategies. Longitudinal applications of the CMT could support this effort by tracing how capabilities evolve over time while interacting with contextual factors such as regulations, market dynamics, or supply chain configuration.

Such insights could help identify key inflection points in CE development and inform the timing and tailoring of interventions.

Researchers could focus on the continuing development and digital integration of the CMT artifact, including user interfaces, dashboards, or compatibility with decision-support systems.

Finally, the theoretical framing of the CMT as a sensemaking framework opens pathways for research into cumulative organizational learning. Future studies could investigate how repeated use of the CMT facilitates reflection, internal alignment, and strategic adaptation over time. This research agenda can provide a deeper understanding of how frameworks like the CMT scaffold transition through organizational sense-making processes.

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Appendices

Appendices

A Glossary of Terms

Capability | The organizational skills, routines, and processes that enable a firm to deploy and coordinate resources effectively in order to achieve specific objectives. Unlike dynamic capabilitiess, which emphasize adaptation and change, ordinary capabilities focus on the efficient execution of existing activities (Teece, 2014; Winter, 2003).

CE Performance Circular Economy (CE) | Performance is defined as a firm's ability to generate environmental, economic, and social value by effectively implementing circular principles across its operations and value chain (Kristoffersen et al., 2021; Potting et al., 2017; Uhrenholt et al., 2022).

Circular Business Model | Business models designed to decouple economic value creation from material consumption and waste, by leveraging strategies such as reuse, remanufacturing, product lifecycle extension, leasing or product-as-a-service. They aim to maintain or increase value while reducing resource inputs and environmental impact (Bocken et al., 2014; World Economic Forum, 2014).

Circular Capabilities | Firm-level abilities that enable the implementation and scaling of CE principles through the reconfiguration of resources, processes, and business models, in line with dynamic capabilities theory (Eisenhardt & Martin, 2000; Teece, 2007). Prior literature also refers to CE capabilities (Bocken et al., 2025; de Arroyabe et al., 2021). In this dissertation, both terms are treated as interchangeable; however, *circular capabilities* is adopted as the primary term for consistency.

Circular Economy (CE) | An economic system aimed at maintaining the value of products, materials, and resources in the economy for as long as possible, while minimizing waste generation (Geissdoerfer et al., 2017). In this dissertation, the term *CE transition* is consistently used to denote the systemic shift to a circular economy. The broader notion of a *circular transition*, often found in policy and academic discourse, is treated here as equivalent but less precise.

Circular Maturity | The extent to which a firm has developed and integrated circular capabilities across organizational dimensions in a structured and progressive manner. Circular maturity is conceptualized as a multidimensional, dynamic, capability-based construct at the firm level that reflects the staged development of organizational capabilities enabling firms to advance their circular transition over time and improve CE performance (Eisenhardt & Martin, 2000; Sehnem et al., 2020; Teece, 2007; Vinante et al., 2021). This implies that maturity is expressed through the configuration and evolution of capabilities across organizational dimensions and can be represented through staged maturity levels that capture progressive capability development (Becker et al., 2009; de Bruin et al., 2005; Pöppelbuß & Röglinger, 2011). While prior literature also refers to circularmaturity, both terms are treated as interchangeable; however, circular maturity is adopted as the primary term for consistency.

Circular Maturity Tool (CMT) | The integrated tool developed in this dissertation, designed to measure CE capabilities at firm level and validated through empirical research.

Circularity | The extent to which a product, process, organization, or system retains resources in closed loops, thereby reducing waste and the need for virgin inputs. Circularity is typically expressed through indicators or indices (e.g., the Material Circularity Indicator) and reflects the measurable outcomes of implementing CE principles (Ellen MacArthur Foundation, 2015; Haas et al., 2015).

Closed-loop Systems | Systems in which outputs or waste from processes are recirculated as inputs, creating feedback loops that reduce material loss, environmental impact, and dependency on new raw materials. Essential to circular economy models. (Ellen MacArthur Foundation, 2021; Kirchherr et al., 2023).

Conceptual Coherence | The degree to which constructs, dimensions, and terminology are consistently applied across CE Maturity Models (MMs), enabling comparison and synthesis (Vinante et al., 2021).

Cumulative Theorizing | The systematic development of theory that builds on and integrates prior studies to create a coherent and evolving understanding of a phenomenon (Colquitt & Zapata-Phelan, 2007; Post et al., 2020).

Design Science (DS) | A research paradigm that creates and evaluates artifacts (e.g., models, methods, tools) to address organizational problems and contribute to theory (Hevner et al., 2004).

Design Science Validity Framework (DSVF) | A framework for systematically articulating and validating knowledge claims about a design science artifact.

It defines validity as the extent to which knowledge claims about a focal artifact are supported by evidence, and distinguishes between criterion validity (utility of the artifact relative to a reference), causal validity (the extent to which specific design features produce observed outcomes), and context validity (the extent to which these claims hold across intended or multiple contexts) (Larsen et al., 2025).

Dynamic Capabilities | The firm's ability to integrate, build, and reconfigure internal and external resources and competencies to address rapidly changing environments. As a concept, it highlights how organizational processes such as learning, adaptation, and innovation enable continuous renewal and transformation (Teece, 2007; Teece et al., 1997).

Dynamic Capabilities | Theory A theoretical framework that explains how firms achieve and sustain competitive advantage in rapidly changing environments by building, integrating, and reconfiguring resources and capabilities. It extends the Resource-Based View (RBV) by emphasizing the role of dynamic, adaptive, and learning-based processes (Teece, 2007; Teece et al., 1997).

Dynamic View | The tendency of many models to present maturity as a linear, one-off achievement (static), rather than as an iterative and evolving capability (dynamic) (Julkovski et al., 2023).

Empirical Grounding | The degree to which CE maturity research is supported by systematic data collection and analysis, rather than purely conceptual proposals (Kuzma et al., 2021).

Framework | A structured conceptual model that organizes key constructs, dimensions, or relationships within a domain, providing guidance for analysis, evaluation, or decision-making. In the context of CE, frameworks help operationalize abstract principles into practical structures for assessment or implementation (Jabareen, 2009; Uhrenholt et al., 2022).

Human Factors | Organizational and cultural aspects — such as leadership, learning, and employee engagement — that influence the successful implementation of CE but are often underrepresented in existing frameworks (Greven & Andriessen, 2019).

Industrial Symbiosis | A collaborative approach among distinct firms or industrial sectors in which by-products, waste, energy, water, or other underused resources from one entity are used as inputs by another, thereby keeping materials in productive use longer and improving resource efficiency. (Chertow, 2007; Neves et al., 2020).

Integration & Validation | The extent to which a MM is both theoretically integrated and empirically validated. This includes the synthesis of relevant constructs and systematic testing through expert review, pilot studies, and iterative refinement (Hevner et al., 2004).

Large-scale Validation | The extent to which a MM has been empirically tested and validated across a broad and diverse sample of organizations, sectors, and contexts, ensuring robustness and generalizability of results (Sacco et al., 2021).

Maturity Model (MM) | A maturity model is a framework that assists an individual or organization in progressing toward a higher level of maturity (i.e., capability) across dimensions such as people/culture, processes/structures, and objects/technologies, typically through a structured, step-by-step improvement approach (Mettler, 2011; Mittal, Khan, et al., 2018).

Performance Indicators | Quantitative or qualitative measures that evaluate CE performance at product, process, or organizational levels (Kristensen & Mosgaard, 2020).

Practical Usability | The extent to which an MM is practically applicable in organizational contexts, balancing comprehensiveness with ease of completion (e.g., number of variables, clarity, time investment). Tools with fewer but well-structured items are more likely to be adopted and used effectively in practice (Vinante et al., 2021).

Regenerative Design | A design paradigm that goes beyond minimizing negative environmental impacts to restoring, renewing, or revitalizing degraded ecological systems. It emphasizes net-positive effects, systems thinking, and improving the relationships between human activities, built environments, and ecosystems. (Pavez et al., 2024; Plaves et al., 2023).

Resource Retention | The principle of keeping resources (materials, components, products) in use for as long as possible, through strategies such as reuse, repair, refurbishing, remanufacturing, or recycling, to reduce demand for virgin materials and avoid waste. Frequently discussed in CE literature. (Stahel, 2016; World Economic Forum, 2014).

Resource-Based View (RBV) | A theoretical perspective emphasizing the strategic importance of valuable, rare, inimitable, and non-substitutable resources in sustaining competitive advantage (Barney, 1991).

Sensemaking Theory | An organizational theory that explains how individuals and organizations interpret ambiguous or complex environments, construct shared meaning, and guide action under uncertainty. Based on Weick (1995), and later extended by Weick et al. (2005), the theory emphasizes continuous processes of noticing, interpreting, and enacting to make sense of change and complexity.

Small and Medium Enterprise (SME) | The EU defines a SME as a business with fewer than 250 employees, a turnover of less than €50 million, or a balance sheet total of less than €43 million (European Commission, 2020b; Mittal, Khan, et al., 2018). Within this umbrella, There are three different categories: medium-sized, small, and micro-businesses (Dey et al., 2022). These categories are defined by turnover and number of employees.

Systems Thinking | An analytical perspective that views organizations and economies as dynamic, interdependent systems characterized by feedback loops, path dependencies, and emergent behavior. It emphasizes the importance of holistic understanding and adaptive governance in managing complex transitions such as the shift to a circular economy (Baxter & Sommerville, 2011; Kesić, 2016; Meadows, 2008).

Take-back System | Organised mechanisms through which producers, brands, or third parties retrieve used products, components, or materials from end-users at the end of their use phase. These systems enable reuse, remanufacturing, recycling, or safe disposal, and are often implemented under Extended Producer Responsibility (EPR) frameworks. Take-back systems are considered essential enablers of closed-loop supply chains and a functional circular economy (Mayanti et al., 2023; Singarajah et al., 2025).

Take-Make-Waste Model | A linear economic model in which resources are extracted (“take”), transformed into products (“make”), and ultimately discarded as waste (“waste”), with minimal reuse or recovery of materials. Often used in literature critiquing the traditional “linear economy” contrasted with circular economy approaches. (Ellen MacArthur Foundation, 2021; Kirchherr et al., 2023).

Theoretical Integration | The extent to which an MM explicitly builds on and tests established organizational theories (e.g., Resource-Based View, Dynamic Capabilities, Organizational Learning), rather than being solely practice-driven. This dimension addresses a widely acknowledged weakness in many maturity models, which are often developed without a clear theoretical foundation or methodological rigor (Becker et al., 2009; Mettler, 2011).

Theory-Grounded Validation | The extent to which a maturity tool is validated using rigorous scientific methods such as Design Science Research cycles and structural equation modeling, ensuring methodological robustness beyond descriptive or usability-focused testing (Hevner et al., 2004).

B Intellectual Lineage

Figure 2 illustrates the intellectual lineage underpinning the development of the Circular Maturity Tool (CMT). The map organizes the literature into three contribution layers. Foundational works (e.g., Boulding, 1966; Stahel, 2016; Ellen MacArthur Foundation, 2013) established the core principles of circularity, closed-loop systems, and performance economy. Early contributions (e.g., Kristensen and Mosgaard, 2020; Vinante et al., 2021; Sehnem et al., 2020) translated these concepts into operational frameworks, defining indicators and maturity structures for firms. State-of-the-art studies (e.g., Pigosso and McAloone, 2021; Uhrenholt et al., 2022; Kayikci et al., 2022; Julkovski et al., 2023; Bocken et al., 2025) advanced the field through theoretical integration, empirical testing, and tool-based validation.

The lines visualize how knowledge evolves across these layers: Inspired by links (green) denote conceptual influence; Builds on (blue) marks cumulative theoretical or methodological extension; Synthesizes (yellow) represents the integration of multiple prior insights; and Parallel (black) indicates contemporaneous studies addressing similar questions independently.
For instance, the definition and measurement logic proposed in the Ellen MacArthur Foundation (2013) report inspired the product- and process-level indicators reviewed by Kristensen and Mosgaard (2020). The framework by Vinante et al. (2021) is based on these classifications and provides the conceptual foundation for the CM-FLAT tool de-veloped by Sacco et al. (2021). Similarly, Uhrenholt et al. (2022) build on Sehnem et al. (2020) by embedding circular maturity dimensions within the Resource-Based View (RBV), thereby linking operational and strategic perspectives. The MATChE model proposed by Pigosso and McAloone (2021) evolved in parallel with the CE–I4.0 readiness framework by Kayikci et al. (2022); both aim to assess organizational readiness for circular transformation, yet address different contexts, manufacturing firms and technology-enabled SMEs respectively. Castillo-Ospina et al. (2025) are inspired by Uhrenholt et al. (2022)'s capability-based reasoning up to the ecosystem level, focusing on the inter-organizational dynamics of circular transformation. Finally, the large-scale empirical study by Bocken et al. (2025) also evolved in parallel with this dissertation, both pursue data-driven approaches to assess corporate circularity, yet through complementary perspectives, indicator-based measurement and capability-based maturity assessment.
These interrelations show how circular economy research has progressed from conceptual foundations to empirically validated frameworks. The CMT developed in this dissertation synthesizes these streams, combining the measurement rigor of indicator approaches with the dynamic and capability-oriented logic of maturity models into a unified, systemically grounded framework.

C Dissemination and Knowledge Contribution

This table is an overview of the dissemination activities conducted throughout the research path. The table includes (peer-reviewed) publications as well as formal presentations in academic and practice-oriented settings.

Table 33: Overview of Dissemination Activities (Publications and Presentations)

Year	Type	Venue / Title
2019	Conference Presentation	*Measuring Circular Maturity in Logistics Business Models*, ICT and Logistics Covention, Utrecht, the Netherlands
2020	Paper	*Meetbaar maken van de bijdrage van logistiek aan de ontwikkeling van circulaire bedrijfsmodellen*, Tijdschrift Logistiek+ (Tuinstra et al., 2020)
2021	Conference Presentation	*Logistics: The Engine of the Circular Economy*, ICT and Logistics Convention, Utrecht, the Netherlands
2021	Webinar Presentation	*Digital Technology Strategies to Increase Circular Performance*, Circular Economy: How to Design and Organize Circular Material Flows, Delft University of Technology
2022	Masterclasses	*Product Innovation for the Circular Economy*, Eindhoven University of Technology. Eindhoven, the Netherlands
2022	Conference Presentation & Workshop	*Digital Technology Driven Circular Performance*, Innovation conference Logistics, TKI Dinalog, Utrecht, the Netherlands
2022	Conference Presentation	*Hoe digitale technologie gaat helpen om circulair beter te presteren*, Business Software Event, Mikrocentrum, Veldhoven, The Netherlands
2022	Workshop & Presentation	*Assessment and Decision Framework for Circular Design*, Circulair Value Center, Dutch Design Week, Eindhoven, the Netherlands
2022	Webinar	*Circulaire Economie? Hoe meet je dat eigenlijk?*, Process-camp, https://events.webinars.nu/processcamp/circulaire-economie
2022	Conference Presentation	*Measuring Circularity*, Utrecht Science Park Circular Economy Festival, Utrecht University, Utrecht, the Netherlands
2022	Paper & Conference Presentation	*Measuring Circularity: The Gordian Knot of the 21st Century*, Communications of the IIMA, Seattle, United States (Wierikx et al., 2022)

Table 33: Overview of Dissemination Activities (Publications and Presentations) – Continued

Year	Type	Venue / Title
2023	Seminar Presentation	*Circular Performance Measurement Model; Rigor and Relevance*, Service Logistics Forum, Eindhoven, the Netherlands
2023	Workshop & Presentation	*Measuring Circularity: The Gordian Knot of the 21st Century*, European Supply Chain Forum, Eindhoven, the Netherlands
2023	Webinar	*Measuring Circularity: The Gordian Knot of the 21st Century*, VLW – Transport and Logistics Research Days, the annual Dutch academic conference on transportation and logistics
2023	Conference Chair & Presentation	*Leadership Summit Service Logistics Forum, Towards green and resilient service supply chains*, Naaldwijk, the Netherlands (see Appendix L #06)
2024	Seminar Presentation	*Measuring Circularity: The Gordian Knot of the 21st Century, TBK Talks, Utrecht, the Netherlands*
2024	Paper & Presentation	*Measuring Circular Performance on the Organizational Level: A Systemic Framework*, 11th EurOMA Sustainable Operations and Supply Chains Forum, Hamburg, Germany (see Appendix L #06 and #07)
2024	Symposium Presentation	*Meten van Circulaire Volwassenheid en Performance*, Symposium Research Group Process Innovation & Information Systems, Utrecht, the Netherlands
2024	Workshops & Presentation	*Circular Performance Seminar*, official artifact launch (Circular Maturity Tool (CMT) v3), Route Circulair, Utrecht University of Applied Sciences and Eindhoven University of Technology, Utrecht, the Netherlands
2024	Conference Presentation	*Circulaire economie; een samenspel van beleid en praktijk*, Nationaal Gemeentelijk Grondstoffen Congres, Nijkerk, the Netherlands
2024	Workshop	*Meetbaar maken van circulariteit*, Province of Utrecht, Utrecht, the Netherlands
2024	Workshop	*Logistics as the engine of the transition to circular*, celebrating the launch of the book "Werken met Logistiek" (Visser et al., 2024), Dordrecht, the Netherlands
2024	Masterclass	*Summerschool Circular Economy Business Models*, Utrecht University of Applied Sciences, Utrecht, the Netherlands

Table 33: Overview of Dissemination Activities (Publications and Presentations) – Continued

Year	Type	Venue / Title
2024	Presentation	*Logistiek is de motor van de circulaire economie*, VELA (Dutch Association for Logistics Consultants), Biddinghuizen, the Netherlands
2024	Workshop	*Mobiliteit en circulariteit: De weg van circulaire grondstoffen*, Earth Valley Café, ROM Utrecht Region – Dutch Regional Development Agency, Utrecht, the Netherlands
2024	Masterclass	*Circularity and Logistics*, Fontys University of Applied Research, Venlo, the Netherlands
2024	Roundtable & Discussions	*Requirements for circular transitions*, Utrecht Science Park Circular Economy Festival, Utrecht University, Utrecht, the Netherlands
2024	Webinar	*Inzicht in Circulaire Volwassenheid van Bedrijven*, VNO-NCW (The Confederation of Netherlands Industry and Employers)
2024	Presentation	*Circularity and Logistics*, Kennisakkoord Logistiek (Center of Expertise), Utrecht, the Netherlands
2024	Presentations cussions	*Circulariteit meetbaar maken op organisatieniveau*, Projectmarket Research center Digital Business and Media, Utrecht University of Applied Sciences, Utrecht, the Netherlands (promotion video and scientific poster available through online Appendix L #09, #10 and #11)
2025	Presentation	*Relevant & Grondig*, on the occasion of the launch of the first Circular Impact Report (Pape et al., 2025), Route Circulair, Utrecht University of Applied Sciences, Eindhoven University of Technology, Eindhoven, the Netherlands
2025	Paper, Presentation & Workshop	*Samenwerken in de waardeketen als sleutel tot circulaire prestaties*, paper presented at the VLW – Transport and Logistics Research Days, the annual Dutch academic conference on transportation and logistics (available through online Appendix L #02), Tegelen, the Netherlands (Wierikx et al., 2025)
2025	Paper	*A Design Science Approach to Circular Economy Transitions: Developing a Maturity Model for Firms*, Manuscript submitted for publication to Technovation (see Appendix L #03) (Wierikx, Raassens, et al., 2026)
2025	Webinar	*Advancing Design Science: A Circular Economy Maturity Model for Firm Transitions – Development & Deployment*, Alliance of universities of Leiden, Delft and Erasmus Rotterdam (LDE)

Table 33: Overview of Dissemination Activities (Publications and Presentations) – Continued

Year	Type	Venue / Title
2025	Workshop	*Societal impact and Recyclability*, Semicon Workshop New York State - Brainport Region Cooperation, Eindhoven, the Netherlands
2025	Masterclass	*Summerschool Circular Economy Business Models*, Utrecht University of Applied Sciences, Utrecht, the Netherlands
2025	Masterclass	*Circularity and Logistics*, Fontys University of Applied Research, Venlo, the Netherlands
2025	Keynote presentation	*Logistics as the engine of the transition to circular*, ICT and Logistics Convention, Utrecht, the Netherlands
2026	Convention	Circular Entrepreneurship, Werkspoorkathedraal, Utrecht, on the occasion of the launch of the second Circular Impact Report (Smit et al., 2026), Route Circulair, Utrecht University of Applied Sciences, Eindhoven University of Technology, Eindhoven, the Netherlands, where the report was presented to Her Majesty Queen Máxima in the presence of more than 1,200 attendees
2026	Presentation	*Zero emissions? First zero inefficiency Why logistics must become smarter before it becomes cleaner,* Logistics Platform Utrecht (LPU) Spring Event, Amersfoort, the Netherlands
2026	Masterclass	*Logistics: the engine of the circular economy; on the brink of a new way of organizing,* Lifeport, Nijmegen, the Netherlands

D Exploratory Interviews

Table 34: Overview of Participating Organisations

Organisation	Function	Classification	Size (FTE)	Turnover (mio €)
Manufacture of other electrical and electronic cables	VP	2732	77,000	19,000
Accountancy, tax advice and administration	Partner	6920	219,000	29,000
Manufacturing of plastic sheets, foil, tubes and profiles	CEO	2221	400	80
Manufacture of other outerwear	CEO	1413	50	10
Manufacture of machines for metallurgy	VP	2891	32,000	18,000
Advice and support in the field of information technology	CEO	6202	200	40
Manufacture of machinery for construction and mining	Director	2892	1.500	300
Casting of iron	CEO	2451	100	15
Manufacture of paper and cardboard packaging materials; manufacture of corrugated paper and cardboard	Circular Economy Manager	1721	200	50
Developing, producing and publishing software	VP	6201	75	20
Wholesale and trade mediation in car parts and accessories	COO	4531	300	70
University higher education	Professor	8542	7,500	1,000
Manufacture of aircraft and parts	CEO	3030	200	40

E Dimension References

Dimension References

Table 35 presents the dimensions we identified from the literature (see Chapter 3), then clustered into main and subdimensions. The numbers refer to the articles where each dimension features. These articles are listed in Table 15 that can also be viewed in the accompanying Excel file, via the online materials (Appendix L #09).

Table 35: Dimensions and References

Dimension	CE Strategy	People				Operations	
Subdimension		General	Leadership & Culture	Communication	Skills	General	
Adoption of Climate Change							
Business models							
CE strategies	6, 12						
Co-creation							
Customers				11, 19			
Destination attractiveness							
Economic						1, 3, 10, 12, 13, 14, 15, 16, 17, 26	
Economic prosperity						11	
Emissions							
Energy							
Environmental							
Environmental quality							
Facilities (Internal business operations)							
Financing							
Future generations		11					
Governance			9,19, 20, 21, 24, 25, 27				
Innovation							

The numbers correspond to each dimension reference ID number, as shown in Table 15

						Environmental	Strategy
	Products & Services	Innovation & Technology	Value Chain Collaboration	Financing	Internal Operations	Environmental	Strategy
						9	
							11
		4, 9					
		11, 19					
		9					
						11	
					22		
					2, 22		
					1, 3, 8, 10, 12, 13, 14, 15, 16, 17, 26		
					11		
				23			
			2, 23				
	2, 4						

Table 35: Dimensions and References – Continued

Dimension	CE Strategy	People				Operations	
Subdimension		General	Leadership & Culture	Communication	Skills	General	
Internal Culture			23				
Leadership			19, 23				
Local Community Contribution - Sustainable livelihoods							
Manufacturing & Value Chain							
Marcom & Sales				4, 23			
Network Design							
Operations						2, 19, 25	
People		19					
People, Skills & Culture		2, 20, 24, 25, 27	19, 20, 27		2, 25		
Plant, Property, & Equipment Assets							
Policy & Market							
Processes						10, 12, 20, 27	
Product design & visibility Products & Services							
Recover	6, 11						
Recycle	1, 3, 6, 11, 22						
Reduce	1, 3, 6, 11, 22						

The numbers correspond to each dimension reference ID number, as shown in Table 15

						Environmental	Strategy
	Products & Services	Innovation & Technology	Value Chain Collaboration	Financing	Internal Operations	Environmental	Strategy
			9				
	21		21				
	4, 9	4, 9	4, 9				
		25					
	2						
							9, 10, 21
	10, 12, 20, 27	10, 12, 20, 27	10, 12, 20, 27	10, 12, 20, 27			
	4, 9 2, 10, 19, 21, 22, 23, 25, 27	4, 9 21	4, 9				

Table 35: Dimensions and References – Continued

Dimension	CE Strategy	People				Operations	
Subdimension		General	Leadership & Culture	Communication	Skills	General	
Reuse	1, 3, 6, 11, 22						
SCOR dimensions							
Self Efficacy							
Services							
Social		1, 3, 10, 12, 13, 14, 15, 16, 17,26					
Social equity		11					
Stakeholder management			23	23			
Strategy							
Supply Chain & Partnership							
Sustainable development		11				11	
Takeback & End-of-life Strategies	21						
Technical							
Technology							
Traceability & transparency						4, 9	
Use, Support & Maintenance	21						
Value Creation						25	
Waste hierarchy							
Water							

The numbers correspond to each dimension reference ID number, as shown in Table 15

						Environmental	Strategy
	Products & Services	Innovation & Technology	Value Chain Collaboration	Financing	Internal Operations	Environmental	Strategy
		8					
		9					
	2						
							23
	21						2, 10, 19, 20, 21, 23, 24, 27
		2, 4, 24, 25					
					11		
	17						
	10, 19, 20, 21, 23, 24, 25, 27 4, 9	4, 9	4, 9				
	21						21
	25	25	25	25			
					11, 22		
					2, 22		

F Itempool Version 2

The following tables present the items for each dimension. The Mxxx code before the reference is the metric code in work by Vinante et al. (2021). This itempool was created during the alpha Test, when data from various sources was triangulated (see Chapter 3 for more details).

Table 36: Strategy Dimension Items

Code	Item		Reference
s1	Circularity is high on the CEO/ director's agenda.	M167	WBCSD (2018)
s2	There is for example, a risk department in our organization that considers risks and opportunities when transitioning to circular business operations.	M305	Pigosso and McAloone (2021)
s3	Our general strategy is aimed at becoming more circular.	M6	Accenture (2016), Ioannou et al. (2016), Pigosso and McAloone (2021), Singh et al. (2018), Verbeek (2016), and WBCSD (2018)
s4	Our organization has measurable objectives regarding circularity.		New item, based on interviews
s5	Our circular reports are made public.		New item, based on interviews
s6	Our organization has an implementation plan for circularity.	M81	Ioannou et al. (2016) and Ormazabal et al. (2016)
s7	Our organization influences laws and regulations regarding the implementation of circular initiatives.	M111, M198	Pigosso and McAloone (2021)
s8	Circular activities are certified in our organization.	M7	Masi et al. (2018), Mura et al. (2020), Ormazabal et al. (2016), and Zhou et al. (2013)

Table 37: Communication Dimension Items

Code	Item		Reference
c1	Our organization promotes active circular products and services externally.	M199, M229	Fonseca et al. (2018) and Kazancoglu et al. (2018)
c2	Our organization actively promotes the development of circular business models in the market.	M199, M229	Fonseca et al. (2018) and Kazancoglu et al. (2018)
c3	Within our organization, we actively communicate about circularity.	M199, M229	Fonseca et al. (2018) and Kazancoglu et al. (2018)
c4	We share relevant information with suppliers to improve their circularity.		New item, based on interviews

Table 38: Skills Dimension Items

Code	Item		Reference
v1	The employees in our organization have circular skills and knowledge.		Uhrenholt et al. (2022)
v2	People in my organization are open to changing their view of the world.		[openness to learning] Rudd et al. (2018)
v3	People in my organization want to increase their knowledge of circularity.		[openness to learning] Rudd et al. (2018)
v4	People in my organization are curious about circularity.		[openness to learning] Rudd et al. (2018)
v5	People in my organization are open to gaining new knowledge about circularity.		[openness to learning] Rudd et al. (2018)
v6	Our organization has training programs to develop knowledge and skills regarding circular entrepreneurship.	M84, M85	Kazancoglu et al. (2018), Masi et al. (2018), Pigosso and McAloone (2021), Uhrenholt et al. (2022), and Verbeek (2016)
v7	The aim to undertake circularity is supported by everyone in the organization.	M78	Pigosso and McAloone (2021) and WBCSD (2018)

Table 39: Leadership & Culture Dimension Items

Code	Item		Reference
lc1	Employees in our organization feel supported if they have an innovative (circular) idea.		New item, based on interviews
lc2	The ideas introduced about circularity are followed within the organization.		New item, based on interviews
lc3	Employees in our organization are involved in circular initiatives.		New item, based on interviews
lc4	Management is visibly and explicitly committed to circularity.		New item, based on interviews
lc5	Within our organization, circularity is more important than maximizing profit.	M316	[top management commitment] Accenture (2016) and Jun et al. (2006)
lc6	Management makes sufficient resources available for circular initiatives.	M316	[top management commitment] Accenture (2016) and Jun et al. (2006)

Table 40: Products & Services Dimension Items

Code	Item		Reference
ps1	Our organization has an "X as a service" model.		Pigosso and McAloone (2021)
ps2	In our organization, the use of non-renewable resources is avoided when designing products and services, unless this is not possible.	M143	Garza-Reyes et al. (2019)
ps3	When designing products, we take into account the moment when a product is no longer useful.	M138	Ormazabal et al. (2018)
ps4	The products that we design can easily be shared with other users.		Pigosso and McAloone (2021)
ps5	Our organization has implemented a process which structurally evaluates the life cycle of products.	M174	Mura et al. (2020)

Table 40: Products & Services Dimension Items – Continued

Code	Item	Reference
ps6	As an organization we take circularity into account when developing our services.	New item, based on interviews
ps7	Our organization develops and operates platforms that simplify the shared use of products and services.	Pigosso and McAloone (2021)
ps8	Our organization is likely to use and make products smarter.	[willingness to..]Winterich et al. (2019)
ps9	Our organization is willing to use and make products smarter.	[willingness to..]Winterich et al. (2019)
ps10	Our organization is motivated to use and make products smarter.	[willingness to..]Winterich et al. (2019)
ps11	Our organization is likely to extend the lifetime of products and parts.	[willingness to..]Winterich et al. (2019)
ps12	Our organization is willing to extend the lifetime of products and parts.	[willingness to..]Winterich et al. (2019)
ps13	Our organization is motivated to extend the lifetime of products and parts.	[willingness to..]Winterich et al. (2019)
ps14	Our organization is likely to use materials that are useful at the end of their lifespan.	[willingness to..]Winterich et al. (2019)
ps15	Our organization is willing to use materials that are useful at the end of their lifespan.	[willingness to..]Winterich et al. (2019)
ps16	Our organization is motivated to use materials that are useful at the end of their lifespan.	[willingness to..]Winterich et al. (2019)

Table 41: Innovation & Technology Dimension Items

Code	Item		Reference
it1	Recycled, biodegradable and / or renewed materials are used in the production process.	M143	Garza-Reyes et al. (2019)
it2	Our organization uses digital technology to monitor the products it uses.		Pigosso and McAloone (2021)
it3	Our organization uses technology to extend the life of products.		Pigosso and McAloone (2021)
it4	Our organization uses innovative working methods.		[organizational innovation capability, org1] Calik et al. (2017)
it5	Our organization has good processes to integrate new technologies and research findings in the development of products and services.		[organizational innovation capability, org2] Calik et al. (2017)
it6	Our organization is better than our competitors in devising and implementing new ways and systems to manage work and business processes more efficiently.		[organizational innovation capability, org3] Calik et al. (2017)
it7	Our organization offers customers products and services that have unique benefits compared to our competitors.		[organizational innovation capability, prod1] Calik et al. (2017)

Table 42: Value Chain Collaboration Dimension Items

Code	Item		Reference
ks1	The purchase of materials takes into account the lending party's degree of circularity.	M22, M324	Accenture (2016), Garza-Reyes et al. (2019), Mura et al. (2020), and Verbeek (2016)
ks2	To enable circular entrepreneurship, we form collaborations with other companies.	M26, M125, M80, M46, M47	Accenture (2016), Fonseca et al. (2018), Garza-Reyes et al. (2019), Ioannou et al. (2016), Prieto-Sandoval et al. (2018), and Verbeek (2016)
ks3	We encourage our suppliers to develop circular initiatives.		New item, based on interviews

Table 42: Value Chain Collaboration Dimension Items – Continued

Code	Item		Reference
ks4	Together with other companies, we develop new circular solutions.	M26, M125, M80, M46, M47	Accenture (2016), Fonseca et al. (2018), Garza-Reyes et al. (2019), Ioannou et al. (2016), Prieto-Sandoval et al. (2018), and Verbeek (2016)
ks5	We strive to purchase materials that are circular.	M33	Fonseca et al. (2018), Garza-Reyes et al. (2019), and WBCSD (2018)

Table 43: Financing Dimension Items

Code	Item		Reference
f1	Our organization invests in circular initiatives.	M304, M305	Pigosso and McAloone (2021) and WBCSD (2018)
f2	Our organization makes business cases for new circular initiatives.	M78	Pigosso and McAloone (2021) and WBCSD (2018)
f3	Circular revenue models have become the standard in our organization.	M194, M195, M102	Ioannou et al. (2016), Kazancoglu et al. (2018), and Pigosso and McAloone (2021)
f4	The financial and sustainability administration departments are integrated in our organization.		New item retrieved from interview coding

Table 44: Internal Operations Dimension Items

Code	Item		Reference
ib1	Our organization is constantly looking at ways to reduce the amount of facility waste.		New item retrieved from interview coding
ib2	Our organization is constantly looking at ways to recycle or reuse facility materials.		New item retrieved from interview coding
ib3	Our organization is taking measures to reduce the energy consumption of business premises.		New item retrieved from interview coding

Table 44: Internal Operations Dimension Items – Continued

Code	Item		Reference
ib4	Our organization only uses sustainable energy sources to supply energy for our business premises.		New item retrieved from interview coding
ib5	In our organization, employees are rewarded for taking circular initiatives.	M318	Kazancoglu et al. (2018)
ib6	Our organization is constantly working on reducing employees' negative impact on climate.		New item retrieved from interview coding
ib7	In our organization, circularity is a priority when purchasing facility materials.		New item retrieved from interview coding

Table 45: Environmental Dimension Items

Code	Item		Reference
m1	Our organization has a policy for CO_2 emissions.	M24	Bianchini et al. (2019), Kazancoglu et al. (2018), Pauliuk (2018), Rossi et al. (2020), and Smol et al. (2017)
m2	The total greenhouse gas emissions (BKG or GHG) are calculated and expressed in CO2EQ (CO_2 equivalent) at our organization.	M24	Bianchini et al. (2019), Kazancoglu et al. (2018), Pauliuk (2018), and Smol et al. (2017)
m3	Air emissions are monitored in our organization.	M173	Mura et al. (2020)
m4	Our organization uses environmental criteria for reducing energy consumption in design and production processes	M53	Ormazabal et al. (2016, 2018)
m5	Energy consumption is monitored in our organization.	M36	Kazancoglu et al. (2018) and Masi et al. (2018)
m6	Our organization applies environmental criteria for reducing the consumption of * primary raw materials * in the design and improvement of its production processes.	M53	Ormazabal et al. (2016, 2018)
m7	Soil-related emissions are monitored in our organization.	M173	Mura et al. (2020)

Table 45: Environmental Dimension Items – Continued

Code	Item		Reference
m8	Our organization uses environmental criteria for reducing the consumption of *water *in the design and improvement of its production processes.	M53	Ormazabal et al. (2016, 2018)
m9	Our organization has a policy for reducing water consumption.	M18, M37, M258, M260, M261	Bressanelli et al. (2019), Jia and Zhang (2011), Rossi et al. (2020), and Zheng and Zheng (2013)
m10	Waste and rainwater are collected / reused in our organization.	M291	Mura et al. (2020)
m11	Our organization has a water reuse system.	M293	Ormazabal et al., 2016
m12	Water-related emissions are monitored in our organization.	M173	Mura et al. (2020)

The outcome variables of Circular Maturity Tool (CMT) are modeled using the R-Strategies for CE Performance by Potting et al. (2017). Table 46 presents the R-Strategies.

Table 46: CE Performance Capabilities, Derived from Potting et al. (2017)

Code	R-Strategy		Description
r1	R0	Refuse	Making a product (or material) unnecessary by waiving its function.
r2	R1	Rethink	Intensifying the use of a product.
r3	R2	Reduce	More efficient manufacturing of products by processing fewer raw and other materials in these products.
r4	R3	Reuse	Reusing discarded, still good products for the same function.
r5	R4	Repair	Repairing and maintaining broken products, so that they can be reused for their original function.
r6	R5	Refurbish	Refurbishing and modernizing old products.
r7	R6	Remanufacture	Using parts of discarded products in a new product with the same function.

Table 46: CE Performance Capabilities, Derived from Potting et al. (2017) – Continued

Code	R-Strategy		Description
r8	R7	Repurpose	Using discarded products or their parts for a new product with a different function.
r9	R8	Recycle	Processing materials into the same (high) or lower quality.
r10	R9	Recover	Burning materials with energy recovery.

G Survey Data Analysis

Descriptive Statistics The data set's characteristics were examined using descriptive analysis. The dataset consisted of 145 responses from firms participating in the research survey v2 (the beta version). Table 47 presents the descriptive statistics for all variables, encompassing the outcome variables.

Table 47: Variables' Descriptive Statistics (Side-by-Side)

Variable	n	Mean	Std	Min	Max		Variable	n	Mean	Std	Min	Max
s1	142	5,04	1,59	1	7		**f3**	139	3,17	1,81	1	7
s2	130	4,06	1,94	1	7		**f4**	125	3,28	1,94	1	7
s3	143	5,25	1,47	1	7		**ks1**	133	4,29	1,65	1	7
s4	137	3,98	1,90	1	7		**ks2**	132	5,18	1,50	1	7
s5	126	3,31	2,13	1	7		**ks3**	130	4,71	1,61	1	7
s6	134	3,46	1,93	1	7		**ks4**	127	4,38	1,79	1	7
s7	129	3,28	1,99	1	7		**ks5**	135	4,59	1,62	1	7
s8	129	3,96	2,15	1	7		**it1**	130	4,67	1,67	1	7
v1	145	4,43	1,48	1	7		**it2**	128	3,74	1,96	1	7
v2	143	5,42	1,11	1	7		**it3**	130	4,41	1,85	1	7
v3	138	5,44	1,15	1	7		**it4**	141	5,04	1,61	1	7
v4	140	5,31	1,34	1	7		**it5**	133	3,66	1,73	1	7
v5	141	5,60	1,11	1	7		**it6**	122	3,89	1,72	1	7
v6	137	3,07	1,54	1	7		**it7**	139	4,83	1,62	1	7
v7	136	4,51	1,59	1	7		**ib1**	144	5,01	1,52	1	7
lc1	137	5,26	1,22	1	7		**ib2**	143	5,02	1,50	1	7
lc2	137	5,00	1,24	1	7		**ib3**	142	5,70	1,44	1	7
lc3	139	4,73	1,59	1	7		**ib4**	130	4,32	1,80	1	7
lc4	142	4,71	1,64	1	7		**ib5**	135	3,28	1,65	1	7
lc5	140	3,42	1,71	1	7		**ib6**	140	4,26	1,62	1	7
lc6	137	4,57	1,58	1	7		**ib7**	132	4,09	1,52	1	7
c1	136	4,57	1,73	1	7		**m1**	130	4,35	1,98	1	7
c2	139	3,82	1,68	1	7		**m2**	115	3,92	2,14	1	7
c3	144	4,47	1,62	1	7		**m3**	115	3,10	1,83	1	7

Table 47: Variables' Descriptive Statistics (Side-by-Side) – Continued

Variable	n	Mean	Std	Min	Max		Variable	n	Mean	Std	Min	Max
c4	127	4,01	1,65	1	7		m4	122	4,07	1,84	1	7
ps1	130	2,49	1,73	1	7		m5	129	5,23	1,61	1	7
ps2	127	4,07	1,84	1	7		m6	120	3,85	1,71	1	7
ps3	131	4,34	1,92	1	7		m7	109	2,95	1,76	1	7
ps4	129	3,94	1,98	1	7		m8	119	3,74	1,82	1	7
ps5	120	3,54	2,07	1	7		m9	134	3,99	1,76	1	7
ps7	132	2,80	1,71	1	7		m10	128	2,73	1,79	1	7
ps8	142	5,51	1,37	1	7		m11	124	2,49	1,73	1	7
ps9	142	5,77	1,27	1	7		m12	116	2,87	1,81	1	7
ps10	143	5,68	1,23	1	7		r1	145	3,63	1,49	1	7
ps11	137	5,15	1,57	1	7		r2	145	3,30	1,59	1	7
ps12	139	5,40	1,37	1	7		r3	145	3,78	1,51	1	7
ps13	139	5,50	1,24	1	7		r4	145	4,04	1,70	1	7
ps14	132	5,26	1,42	1	7		r5	145	4,55	1,77	1	7
ps15	137	5,47	1,32	1	7		r6	145	3,63	1,95	1	7
ps16	139	5,45	1,33	1	7		r7	145	3,77	1,83	1	7
f1	138	4,89	1,68	1	7		r8	145	3,37	1,81	1	7
f2	130	4,41	1,80	1	7		r9	145	4,60	1,85	1	7
							r10	145	3,38	2,11	1	7

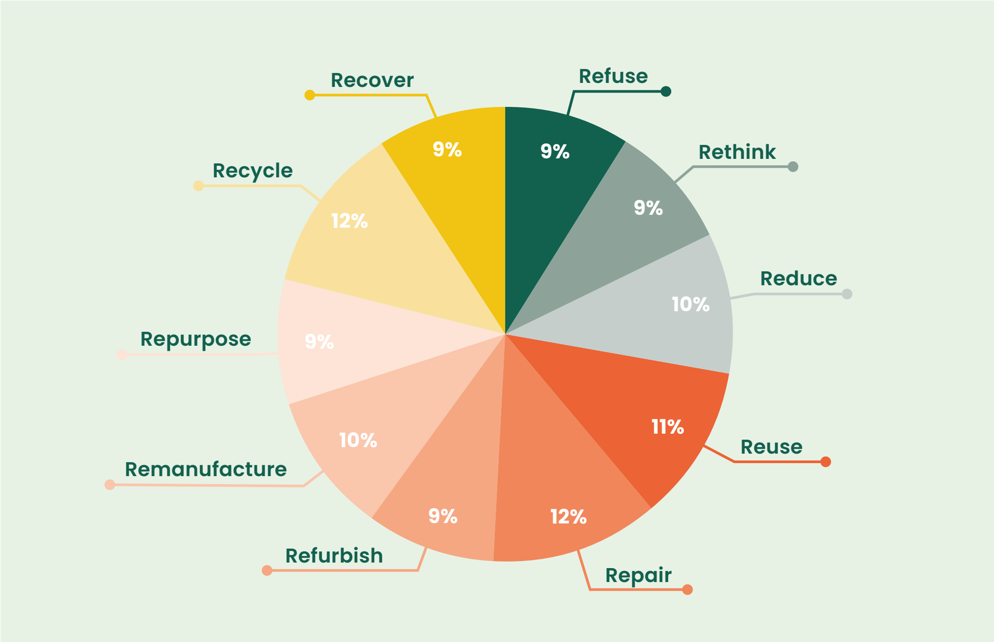
Applying Formula 1 (see section 4.3.2), the Likert scores corresponding to each variable were converted into maturity levels. Subsequently, the maturity levels were computed for each variable and for each dimension, as illustrated in Figure 11.
The mean systemic circular maturity score for the firms participating in the survey was 2.78 on a scale of 5.00. This translates to an average circularity of 55.6% for these firms.[2]

2 Converting maturity scores to percentages is common practice in various Maturity Models (MMs). This approach is a consistent means of assessing an organization's capabilities and simplifies benchmarking and comparative analysis in various firms (Ardoq, 2024; Organisation for Economic Co-operation and Development, 2021)

Figure 11: Maturity Level per Dimension

The outcome metrics capture to what extent each firm adopts the various R-Strategies outlined in Table 46. The options were: (1) Not achieved at all, (2) Not achieved, (3) Slightly not achieved, (4) Neutral, (5) Somewhat achieved, (6) Achieved, (7) Fully achieved. Figure 12 presents the distributed level of R-Strategy adoption.

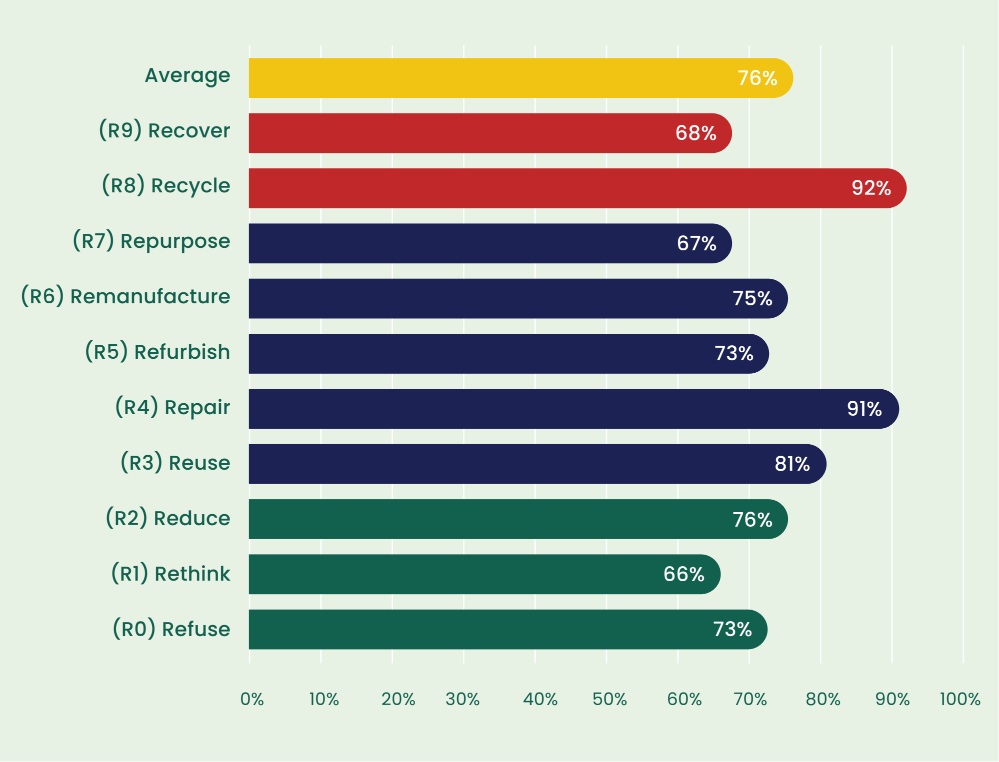
Figure 12: Distribution of Adoption of R-Strategies



Based on Figure 13, the analysis revealed that firms adopted 76% of the 10 possible R-Strategies. Specifically, for pre-use, smarter product use, and manufacturing strategies (R0, R1, and R2), the adoption rate averaged 71%. Strategies focused on extending a product's lifespan and its components during use (R3, R4, R5, R6, and R7) had an average adoption rate of 77%, while post-use material application strategies (R8 and R9) boasted an average adoption rate of 80%. Evidently, the respondents adopted the most effective strategies (R0, R1, and R2) less frequently, whereas the least intensive strategies (R8 and R9) had the highest adoption rate. Remarkably, R8 (Recycling) had a particularly high 92% adoption rate. As illustrated in Figure 12, the adoption rate in various R-Strategies was relatively evenly spread, ranging from 9% to 12%. Since this beta test was one of the initial efforts to gather data on circular performance, there was a certain bias regarding the firms involved in the study. It is quite probable that many survey respondents were early adopters who had already engaged with Circular Economy (CE) practices.[3]

3 This bias is often referred to as the pro-innovation bias as described by Rogers (2003)

Figure 13: *R-Strategy Adoption Score*



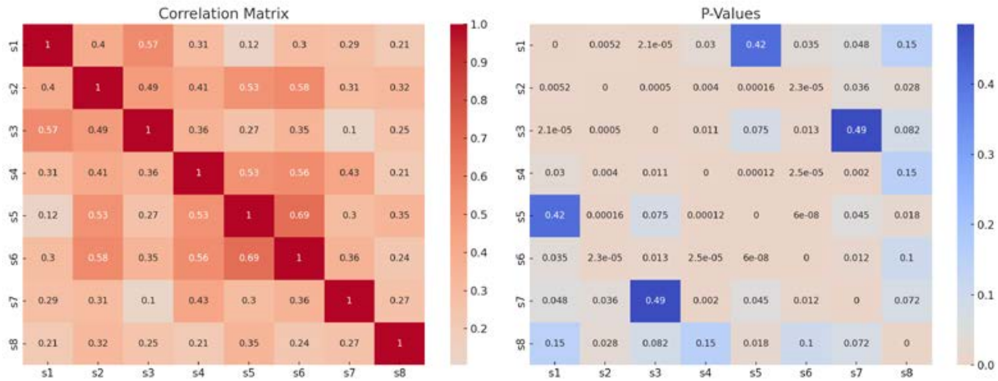
Correlation

The interrelationship between the variables across each dimension was also analyzed. Figures 14 through 24 display heatmaps on the left, and the correlation matrix for each dimension with the p-value matrix on the right. Spearman's rank correlation was selected over Pearson's correlation due to the ordinal nature of the data, particularly the use of Likert-scale responses. Likert scales represent ordered categories but do not assume equal intervals between response levels, making non-parametric methods such as Spearman's correlation more appropriate (Boone & Boone, 2012).

Pearson's correlation assumes linearity and normally distributed data, assumptions often violated in Likert-scale datasets (Norman, 2010). Additionally, Hauke and Kossowski (2011) argue that Spearman's method is more robust for outliers and skewed distributions, making it better suited for non-continuous data.

Furthermore, Sullivan and Artino (2013) emphasize that Likert-scale data should be treated as ordinal rather than interval, reinforcing the need for rank-based correlation methods such as Spearman's.

Figure 14: Strategy Correlation

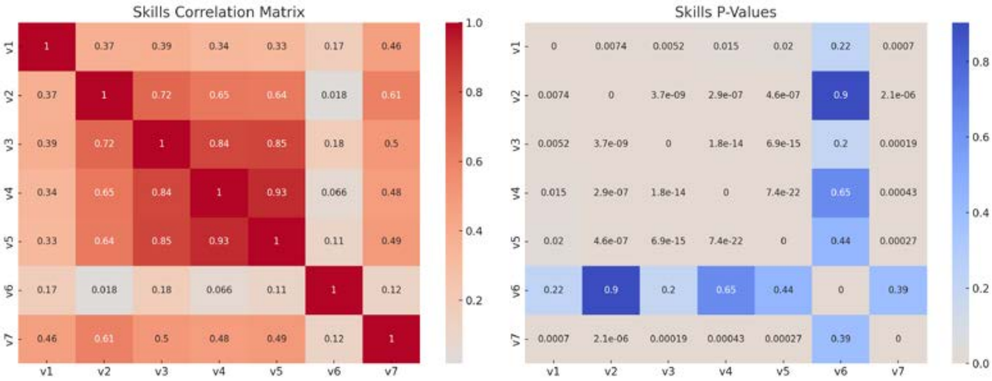


The Strategy heatmap in Figure 14 can be compared with Table 36 describing the strategy-related variables and associated key circular capabilities. This Strategy heatmap, combined with p-values and Table 36, revealed key insights on strategies for adopting CE principles. A strong, statistically significant correlation ($p < 0.05$) was observed between s3 (General strategy for circularity) and s4 (Measurable circular objectives), indicating that firms integrating CE in their strategic vision tend to establish quantifiable targets. Similarly, s6 (Implementation plan) and s8 (Circular certification) showed alignment, suggesting structured execution fosters certification efforts.

However, p-values highlighted that some assumed relationships lack statistical strength. The weak, non-significant link between s5 (Public circular reports) and s3 (Strategic ambition) suggests that transparency in reporting does not necessarily translate into deeper strategic commitment. Furthermore, the moderate but non-significant correlation between s2 (Risk governance) and s7 (Regulatory influence) implies that firms do not always develop risk management structures before engaging with policymakers.

From a capability perspective (Table 36), the findings emphasize that structured governance and measurable objectives are fundamental to CE maturity. Yet, firms may prioritize flexibility over formal certification (s3 vs. s8), and reporting efforts (s5) do not always equate to strategic transformation. This underscores the need for firms to bridge transparency with actionable implementation and balance ambition with regulatory compliance for a coherent CE transition.

Figure 15: Skills Correlation



The Skills heatmap and p-values in Figure 15, combined with Table 38, offer insights into the impact of employee competencies in circular CE transformation. A strong positive and statistically significant correlation ($p < 0.05$) was evident between v1 (Circular skills and knowledge) and v6 (Training programs), indicating that firms with structured training programs tend to have employees with higher circular competency levels. Similarly, v2 (Openness to learning) is positively associated with v5 (Willingness to gain knowledge), suggesting that a receptive organizational culture fosters deeper engagement in CE practices.

However, not all relationships are statistically significant. The link between v3 (Desire to increase circular knowledge) and v7 (Organization-wide CE ambition) is weaker, with p-values above 0.05, indicating that individual employee curiosity does not necessarily translate into collective strategic ambition. This suggests that firms must do more than encourage knowledge acquisition, they must embed circular thinking into broader organizational structures.

From a capability perspective (Table 38), the findings emphasize that structured training programs (v6) and cultural openness (v2, v5) are fundamental enablers of CE adoption. Yet, the weak statistical ties between individual motivation (v3, v4) and systemic ambition (v7) indicate a gap between skill development and circular strategy execution. This underscores the need for firms to align skills training with strategic intent to ensure that knowledge translates into practical CE adoption.

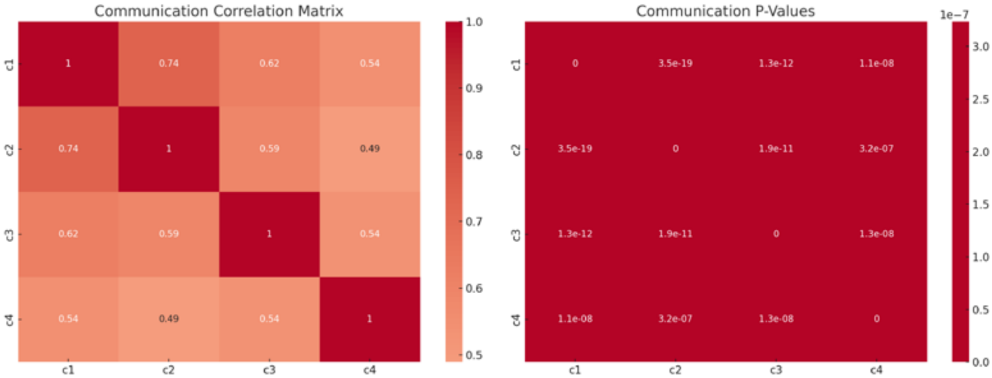
Figure 16: Leadership & Culture Correlation

The Leadership & Culture heatmap in Figure 16, when analyzed alongside p-values and Table 39, highlighted key relationships shaping circular leadership effectiveness. A strong and statistically significant correlation ($p < 0.05$) was observed between lc1 (Feel-ing supported) and lc5 (CE More important than profit). This confirms that leadership awareness strongly influences the formalization of circularity within performance measurement, reinforcing the need for accountability at the top management level.

Similarly, a positive and significant correlation existed between lc2 (Follow up ideas) and lc4 (Visible management), indicating that visible leadership commitment is crucial for ensuring ongoing support for circular initiatives. Moreover, the relationship between lc3 (Employee involvement) and lc6 (Resources available) suggests that structured in-ternal communication fosters a culture where employees are incentivized to engage in CE practices.

From a capability perspective, these findings emphasize that leadership awareness, structured commitment, and performance-based incentives play a vital role in CE adoption. The statistical significance of lc1 and lc5 highlights that firms embedding CE into strategic KPIs demonstrate a more mature and structured circular leadership approach. This underscores the importance of moving beyond basic awareness towards embedding CE principles into leadership evaluation metrics for a sustained circular transition.

Figure 17: Communication Correlation

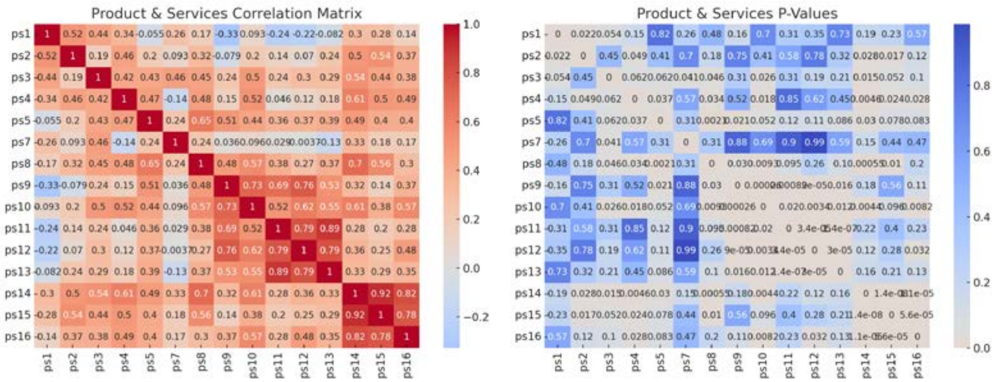


The communication heat map in Figure 17, combined with its p-values and the description of the items in Table 37, highlight key relationships in the way firms engage stakeholders in adopting CE principles. A strong and statistically significant correlation ($p < 0.05$) was observed between c1 (External promotion products and services) and c2 (External promotion Circular Business Models (CBMs)), confirming that firms investing in internal awareness programs are also more likely to engage in external communication efforts. This underscores the idea that a strong internal culture around CE positively influences external messaging strategies.

Furthermore, a significant positive relationship exists between c3 (Transparent internal communication) and c4 (Supplier information sharing), suggesting that transparency in internal CE communication fosters greater external engagement. This implies that firms that prioritize clear internal messaging are more likely to cultivate meaningful part-nerships with external stakeholders.

From a capability perspective, these findings emphasize that internal transparency, structured awareness programs, and external stakeholder engagement are fundamental enablers of successful CE communication. The statistical significance of c1 and c2 high-lights that firms taking a structured approach to internal awareness also tend to communicate their circular ambitions externally. This reinforces the need for firms to align internal messaging with external communication strategies for a coherent and impactful CE transition.

Figure 18: *Products & Services Correlation*



The Products & Services heatmap in Figure 18, analyzed alongside p-values and Table 40, revealed strong correlations between several CE related product strategies. However, despite these strong correlations, none of them was statistically significant ($p > 0.05$), as indicated by the blue p-values. This suggests that while some variables may appear related in the dataset, their relationships cannot be confirmed with statistical confidence.

One of the strongest correlations was between ps3 (Product end-of-life considera-tion) and ps5 (Structural evaluation of product life cycle). While these variables align conceptually, suggesting that firms considering product end-of-life also focus on lifecycle evaluation, statistical testing does not confirm this as a reliable pattern across firms. Similarly, ps8 (Smart product use) and ps11 (Extending product lifetime) exhibited a high correlation, implying that firms investing in smart technologies tend to focus on prod-uct longevity. However, with a non-significant p-value, this relationship lacks statistical robustness.

Another notable yet non-significant correlation was between ps7 (Platform-based sharing models) and ps14 (Material reuse at end-of-life). The correlation suggests that firms promoting shared use models are also likely to focus on material recovery, but the lack of statistical significance ($p > 0.05$) means this is not a consistent trend across firms.

From a capability perspective, these findings indicate that while firms show logical alignment between CE product strategies, the absence of statistical significance suggests that these relationships are not universally strong in different firms. This highlights the need for deeper structural integration of CE principles, ensuring that firms not only explore circular-Strategies but also develop robust implementation pathways that lead to measurable, statistically valid relationships.

Figure 19: Finance Correlation

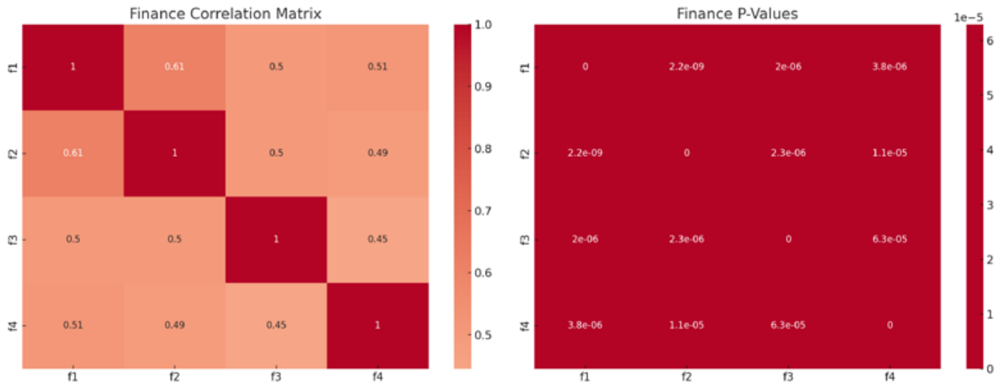


Figure 19 displays the Finance heatmap and its p-values and was analyzed in conjunction with Table 43. The analysis revealed significant interrelations between key financial mechanisms supporting CE adoption. All p-values in the finance heatmap were statistically significant ($p < 0.05$), confirming that the observed correlations reliably represent actual financial patterns in circular businesses.

A strong and statistically significant correlation existed between f1 (Investment in circular initiatives) and f2 (Business cases for circularity), indicating that firms that allocate capital to CE efforts also formalize business cases to justify and sustain these investments. This suggests that financial decision-making in circular firms is systematic and data-driven, ensuring economic viability while advancing sustainability. Another notable relationship was between f3 (Circular revenue models) and f4 (Integrated financial and sustainability administration), emphasizing that firms adopting circular revenue models also tend to embed sustainability accounting into their financial structures. This highlights a mature financial integration where economic performance is evaluated alongside environmental impact.

From a capability perspective, these findings underscore that investment strategies, financial governance, and integrated reporting mechanisms are essential enablers of circular finance. The universal statistical significance confirms that financial maturity in CE firms follows structured and interdependent pathways, making it a critical pillar for scaling circular-Strategies successfully.

Figure 20: Value Chain Collaboration Correlation

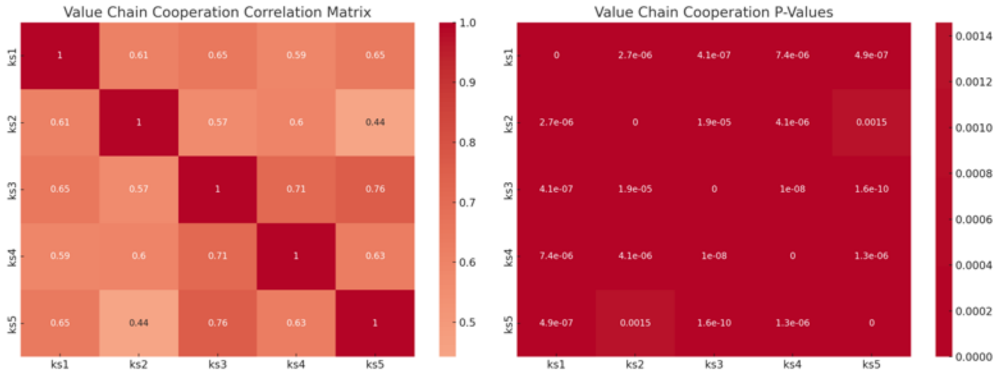


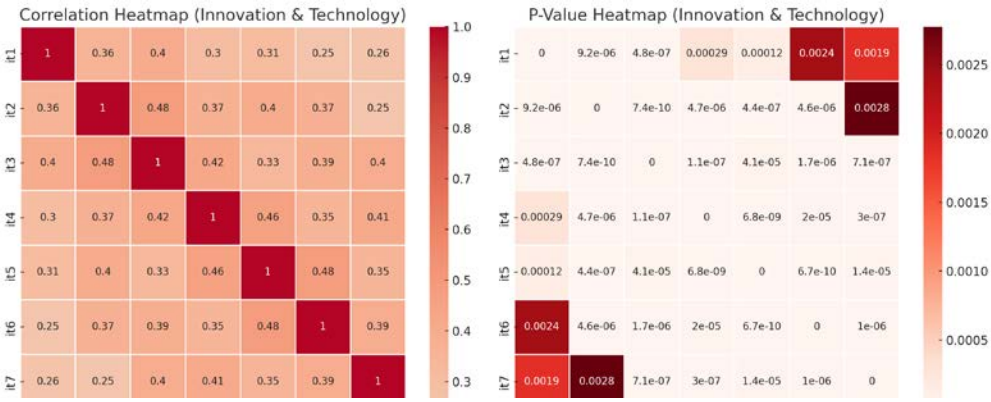
Figure 20 shows that all p-values are statistically significant ($p < 0.05$), and the relationships between variables are robust and meaningful. Together with the description of the items in Table 42, they provide key insights into collaborative efforts to transition to a CE. A strong and statistically significant correlation exists between ks2 (Collaboration with other firms) and ks4 (Development of new circular solutions with partners). This highlights that firms engaging in cross-firm collaboration are also more likely to co-develop innovative circular-strategies. Similarly, ks3 (Encouraging suppliers to develop circular initiatives) is closely linked with ks5 (Ensuring purchased materials are circular), indicating that supplier participation is a critical driver in securing circular material supply.

Another significant relationship was observed between ks1 (Considering the circularity of suppliers when purchasing materials) and ks5 (Circular procurement strategies), reinforcing that firms which assess supplier circularity also actively implement purchasing strategies aligned with CE principles.

From a capability point of view, the results highlight that engaging with suppliers, collaborating among firms, and jointly developing circular solutions are essential to enable circular value chains. Figure 13's statistically significant relationships universally confirm that firms maintaining robust cooperation networks exhibit structured and purposeful circular integration. This highlights the need for firms to build and enhance supplier partnerships and collaborative innovation in order to expand their CE efforts successfully. Left Heatmap: the Correlation Matrix displays the correlation coefficients between variables. Red indicates a strong positive correlation, while blue (not present here) would indicate negative correlations. For example, it5 (Integration of new technologies) and it6 (Process innovation efficiency) have a moderate correlation of 0.48, suggesting a relationship between these aspects of innovation.

Right Heatmap: the P-Value Matrix, shows the statistical significance of the correlations. All p-values are very low ($p < 0.05$), in-dicating that all correlations are statistically significant. This means it is unlikey that these relationships occurred by chance.

***Figure 21:** Innovation & Technology Correlation*



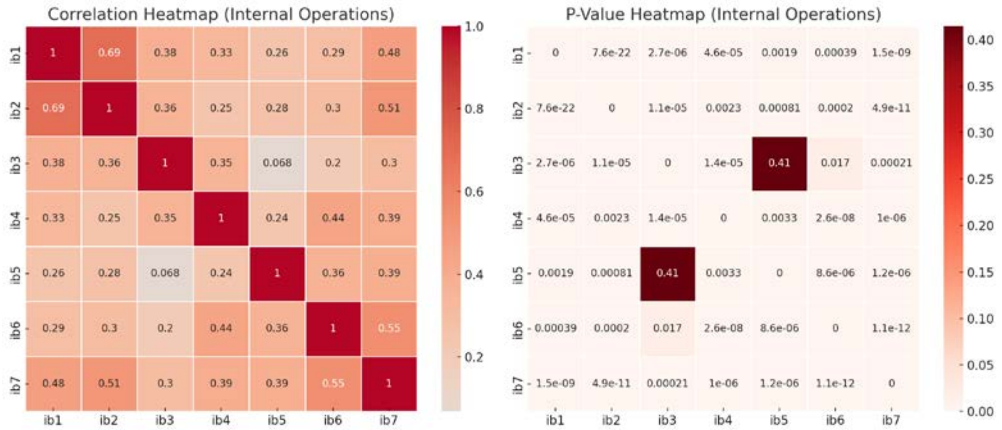
The Innovation & Technology heatmap in Figure 21, analyzed alongside its p-values and Table 41, provides statistically validated insights into the integration of technological advancements within firms' CE strategies.
A strong and statistically significant correlation ($p < 0.05$) was observed between it5 (Integration of new technologies) and it6 (Process innovation efficiency), suggesting that firms adopting technological advancements also tend to prioritize efficiency-driven innovations. Similarly, it3 (Technology use to extend the useful life of the product) shows a meaningful correlation with it4 (Investments in circular technologies), highlighting that firms that focus on extending the useful life of the product often invest in enabling circular technologies.

Another notable relationship exists between it1 (Adoption of circular technology) and it2 (Digital technology for circular monitoring), which confirms that firms integrating digital monitoring tools are more likely to expand their broader portfolio of circular technologies.

These findings emphasize that technology adoption, process innovation, and circular investments are interconnected enablers of CE transformation. The statistically significant p-values ($p < 0.05$) for all relationships confirm the robustness of these correlations, highlighting that firms that incorporate technological advancements into their innovation strategies do so in a structured and systematic way.

This underscores the importance of aligning technology adoption with broader orga-nizational innovation strategies to ensure circular maturity in all dimensions.

***Figure 22**: Internal Operations Correlation*



The Internal Operations heatmap in Figure 22, when considered in conjunction with its p-values and Table 44, offers a statistically supported insight into how firms enhance their internal processes for CE efficacy.

A statistically significant and robust relationship ($p < 0.05$) was identified between ib1 (Reducing facility waste) and ib2 (Recycling or reusing facility materials). This indicates that firms concentrating on efficiency tend to standardize their internal processes. Likewise, a strong positive correlation was evident between ib6 (Reducing employees' climate impact) and ib7 (Prioritizing circularity in facility purchases), underscoring that businesses enhancing operational workflows also prioritize process integration. There was also a notable correlation between ib4 (Use of sustainable energy sources) and ib6 (Reducing employees' climate impact), indicating that firms employing digital technologies are more inclined to integrate lean operational practices. This underscores the impact of digital transformation in enhancing circular efficiency.

However, the correlation between ib3 (Reducing energy consumption of premises) and ib5 (Rewarding employees for circular initiatives) was weaker and statistically non-significant ($p = 0.41$). This suggests that while automation plays a role in process optimization, it does not necessarily drive improvements in resource allocation efficiency in a consistent manner between firms.

These results highlight the crucial role of process standardization, digitalization, and workflow integration as fundamental drivers of operational circularity. The presence of statistically significant p-values ($p < 0.05$) for most correlations indicates that firms im-plementing CE principles in their internal processes adopt a methodical and organized approach. This illustrates the need to synchronize process efficiency with digital transformation and workflow integration to achieve circular maturity in all operational aspects.

***Figure 23:** Environmental Correlation*

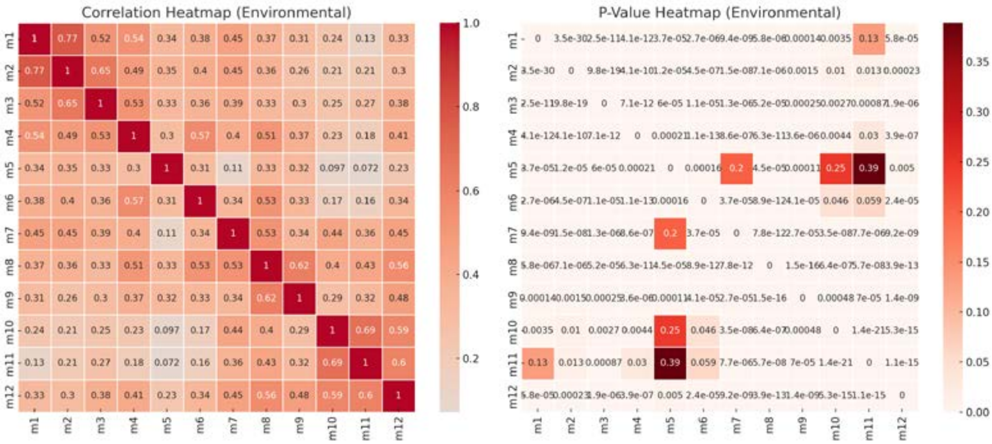


Figure 23's environmental heatmap, examined with its associated p-values and Table 45, delivers a statistically supported insight into incorporating environmental sustainability practices within corporate operations.

A strong and statistically significant correlation ($p < 0.05$) was observed between m1 (Policy for CO_2 emissions) and m2 (Calculation and reporting of greenhouse gas emissions), indicating that firms actively tracking their environmental impact are more likely to participate in structured sustainability reporting. Similarly, m8 (Reducing water consumption in production design) and m9 (Policy for reducing water consumption) exhibited a strong correlation, reinforcing the notion that firms adopting circular material strategies also focus on minimizing waste generation.

Another notable relationship existed between m4 (Reducing energy consumption in design and production) and m6 (Reducing primary raw material use in production), confirming that firms implementing sustainable production methods are also improving their resource efficiency. This underscores the role of CE principles in reducing environmental footprints.

However, the correlation between m5 (Monitoring energy consumption) and m7 (Monitoring soil-related emissions) is weaker and statistically non-significant ($p = 0.20$). This suggests that while energy efficiency and emission reduction are conceptually aligned, they do not consistently co-occur across firms in a statistically reliable way. These results highlight the pivotal roles that environmental monitoring, efficient use of resources, and integration of circular materials play in driving sustainable operations. With most of the relationships showing statistically significant p-values ($p < 0.05$), evidently firms that integrate CE principles in their environmental strategies approach this integration in a well-organized and methodical way. This emphasizes the need to coordinate sustainability reporting, optimize resources, and ensure material circularity to achieve comprehensive environmental advancement in all aspects of operations.

Figure 24: R-Strategy Correlation

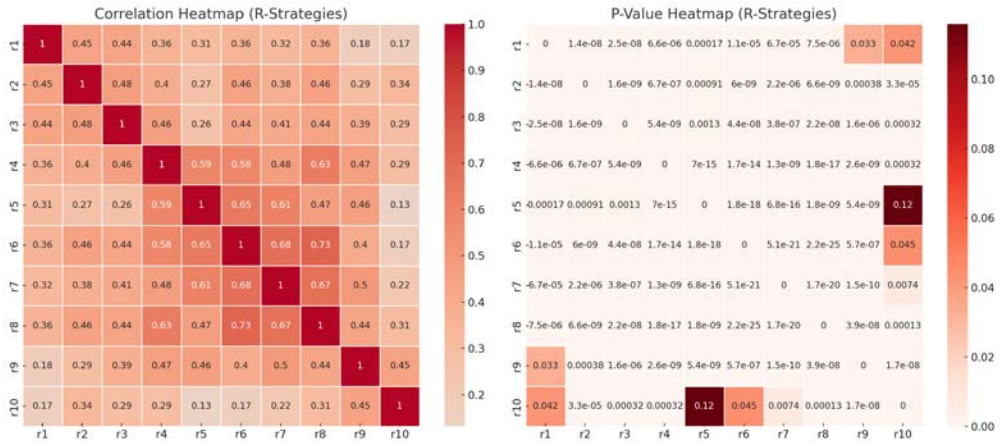


Figure 24 presents a heatmap of R-Strategies that, together with relevant p-values and Table 46, provides a statistically backed perspective on how businesses employ R-Strategies in their operations.

A strong and statistically significant correlation ($p < 0.05$) was observed between r6 (Refurbishing and modernizing old products) and r8 (Using discarded products or parts for a new function — Repurpose), suggesting that firms investing in refurbishing practices also tend to prioritize repurposing efforts. Similarly, r5 (Repairing and maintaining broken products) and r6 (Refurbishing and modernizing old products) exhibited a notable correlation, reinforcing the idea that firms implementing repair strategies also integrate refurbishing initiatives as part of their circular business model.

Another significant relationship exists between r4 (Reusing discarded, still good products for the same function) and r6 (Refurbishing and modernizing old products), confirming that firms engaging in reuse practices also extend their involvement into product refurbishing. This highlights a structured approach to extending product life cycles, where firms implementing one R-strategy often complement it with another.

However, the correlation between r9 (Processing materials into the same or lesser quality — Recycle) and r1 (Refusing unnecessary products or functions) was statistically significant (p = 0.033), yet the strength of the relationship was relatively weak. This suggests that while there is a measurable association, firms focusing on recycling do not necessarily align closely with those prioritizing refusal strategies as a means of waste prevention.

Furthermore, r10 (Burning materials with energy recovery — Recover) and r4 (Reusing discarded, still good products for the same function) exhibited a weak and statistically non-significant correlation (p = 0.12), indicating that firms emphasizing reuse do not consistently engage in energy recovery strategies.

From a capability standpoint, these results highlight that the principal foundations of CE strategies are reusing, refurbishing, and recycling. The majority of statistically significant p-values ($p < 0.05$) affirm that firms systematically and methodically incorporate CE principles within their recovery plans. This highlights the critical role of harmonizing strategies for material reuse, repair, and recycling to enhance resource efficiency, while acknowledging that certain approaches like energy recovery might operate separately from conventional circular methods.

H Qualitative Analysis

The qualitative analysis is part of the beta test, described in Chapter 4.

Extension to the Strategy Dimension Narrative
The qualitative findings enhance, confirm, and challenge the existing strategy's narrative. A notable addition, not directly captured by the measurement items, is the role of cross-functional collaboration in circular strategy development. One respondent emphasized:

> *"We realized that circularity is not just an R&D thing; it requires input from finance, logistics, and even marketing to make it work." (X021, RM102)*

This suggests that successful Circular Economy (CE) strategies require integrated contributions across business functions, fostering a systemic and implementable approach. The heatmap analysis indicated a strong relationship between *General Strategy for Circularity (s3)* and *Measurable Circular Objectives (s4)*, which was confirmed by interview data:

> *"Having a circular ambition is great, but without KPIs, it's just talk. We had to define clear objectives, like reducing virgin material use by 20% within three years." (X017, RC054)*

Similarly, the correlation between *Implementation Plan (s6)* and *Circular Certification (s8)* was validated:

> *"The moment we formalized our strategy and set milestones, obtaining circular certification became a logical next step." (X010, RM037)*

However, contradictions emerged. The weak heatmap correlation between *Public Circular Reports (s5)* and *Strategic Ambition (s3)* was disputed by qualitative insights, as public reporting appears to strengthen internal commitment:

> *"Once we started publishing annual circularity reports, it forced us to take strategy more seriously because we knew investors and customers would scrutinize our progress." (X005, RC091)*

In addition, several firms highlighted the importance of proactive regulatory engagement. This finding underscores the role of governance, not as a secondary, but as a strategic driver. Interview data supported the relevance of both *Regulatory Influence (s7)* and internal *Risk and Opportunity Management Structures (s2)*:

> *"We learned the hard way that regulatory shifts could derail our circular strategy. Now, we actively map risks and engage with policymakers early on." (X011, RM025)*

These insights emphasize that firms advancing in CE strategy prioritize interdisciplinary collaboration, KPI-driven execution, strategic transparency, and proactive governance engagement.

Extension to the Communication Dimension Narrative

The qualitative findings refine and expand the communication dimension by emphasizing transparency, stake-holder engagement, and strategic messaging. A recurring theme is the challenge of greenwashing, which can undermine trust:

> *"We are cautious about what we communicate, greenwashing can erode trust, so transparency is critical." (X002, RC090)*

This highlights the need for fact-based communication backed by measurable data to ensure credibility.

The heatmap analysis shows a strong correlation between *Internal CE communication (c3)* and *Promotion of circular business models in the market (c2)*. Firms emphasized the importance of internal alignment before engaging external stakeholders:

> *"We regularly share updates with employees to ensure they understand and align with our circular goals." (X005, RC006)*

Beyond the measured items, interviewees also underscored the importance of financial framing in communication. Integrating sustainability concepts with monetary value enhances stakeholder engagement and commitment:

> *"Communication is not just about sustainability, it's about showing the monetary and value-driven benefits of circularity." (X003, RM030)*

However, a contradiction emerged regarding communication effectiveness. While the heatmap shows limited correlation between CE messaging (c2) and market impact, firms report that storytelling remains an essential tool:

> *"Storytelling helps us explain the why behind circularity, it's about connecting with people on a deeper level." (X004, RC005)*

These findings suggest that successful CE communication must integrate transparency, financial relevance, and storytelling to maximize effectiveness.

Extension to the Skills Dimension Narrative

The qualitative findings highlight the role of continuous learning and structured training in enhancing CE capabilities. A strong correlation exists between *Circular Skills and Knowledge (v1)* and *Training Programs (v6)*, suggesting that firms investing in structured learning initiatives build stronger circular competencies:

> *"We noticed that employees who participated in our CE training sessions became internal ambassadors, driving circular initiatives in their departments." (X012, RM041)*

Additionally, openness to learning plays a critical role in skill acquisition. The relationship between *Openness to Learning (v2)* and *Willingness to Gain Knowledge (v5)* was confirmed by interviewees:

> *"A key shift happened when our teams became curious about circularity. Instead of seeing it as a compliance task, they started proactively integrating it into their projects." (X008, RC056)*

However, the link between individual curiosity *(v3, v4)* and organization-wide support for circularity *(v7)* remains weak, indicating that skill development alone does not translate into strategic execution:

> *"We have employees eager to learn about circularity, but unless leadership integrates these skills into decision-making, progress remains slow." (X014, RM089)*

This suggests that firms must bridge the gap between training and strategic execution by embedding CE competencies into leadership frameworks and performance evaluations.

Extension to the Leadership & Culture Dimension Narrative

The qualitative findings emphasize that leadership awareness and structured commitment are key enablers of CE adoption. A strong correlation between *Support for employee-driven CE innovation (lc1)* and *Leadership prioritization of CE over profit (lc5)* confirms that top-down values alignment reinforces structured CE strategies:

> ***"We embedded circular KPIs into leadership performance reviews to ensure commitment at all levels." (X014, RM089)***

Similarly, leadership visibility plays a vital role in fostering CE initiatives, with interview data confirming a link between *Commitment to follow through on circular ideas (lc2)* and *Visible leadership commitment (lc4)*:

> ***"When leadership visibly champions CE, employees feel empowered to contribute." (X007, RC020)***

However, a contradiction arose regarding leadership communication. The heatmap suggests a weaker-than-expected relationship between *Employee involvement in CE initiatives (lc3)* and *Management resourcing for CE initiatives (lc6)*, yet firms report that structured messaging fosters a CE-driven culture:

> ***"Clear leadership messaging on CE principles has significantly influenced how our teams approach sustainability." (X011, RM054)***

These findings highlight the importance of embedding CE into leadership evaluation, making commitments visible, and ensuring consistent internal communication to drive cultural transformation.

Extension to the Products & Services Dimension Narrative

The qualitative findings highlight firms' increasing focus on designing for circularity. A strong alignment exists between *End-of-life product consideration (ps3)* and *Lifetime extension of products and parts (ps11)*, confirming that firms recognize the value of extending product usability:

> ***"We now design products with easy disassembly in mind, making repairs and upgrades simpler." (X009, RM048)***

Furthermore, adoption of digital technology is a key enabler of circular products, as evidenced by the link between *Smart product integration (ps8)* and *Technology for lifecycle extension (it3)*:

> ***"By embedding sensors in our products, we track their usage and optimize maintenance, extending their life." (X014, RC061)***

However, a contradiction arose regarding material reuse. While the heatmap shows a weaker correlation between *Material circularity (ps14)* and actual implementation, firms report a strong willingness:

> ***"We aim to reuse materials from end-of-life products, but infrastructure and costs remain a challenge." (X007, RM033)***

These insights suggest that while circular design and smart technologies are advancing, material recovery still faces operational and economic barriers.

Extension to the Innovation & Technology Dimension Narrative
The qualitative findings reinforce the role of technological adoption and process innovation in CE transition. A strong correlation was observed between *Integration of new technologies (it5)* and *Process innovation efficiency (it6)*, suggesting that firms investing in technological advancements also focus on operational efficiency:

> ***"New technologies enable us to reduce waste in production, while also streamlining workflows." (X013, RC074)***

Furthermore, firms embedding circular monitoring tools tend to expand their technology portfolio, as reflected in the relationship between *Adoption of circular materials (it1)* and *Digital technology for circular monitoring (it2)*:

> ***"Using digital tracking allows us to identify reuse opportunities and optimize resource efficiency." (X009, RM051)***

However, contradictions arose in the implementation phase. The heatmap suggests a weaker-than-expected correlation between *Technology use for product life extension (it3)* and *Innovative working methods (it4)*, despite firms expressing strong intent:

> ***"We want to extend product lifecycles, but financial constraints and lack of infrastructure make scaling difficult." (X010, RM066)***

These insights emphasize that while technological innovation drives circularity, firms must bridge investment gaps and infrastructure challenges to fully capitalize on these advancements.

Extension to the Value Chain Collaboration Dimension Narrative

The qualitative findings reinforce that strong collaboration across the supply chain is critical for CE success. A notable correlation was observed between *Collaboration with suppliers (ks3)* and *Circular procurement strategies (ks5)*, highlighting that supplier engagement drives material circularity:

> ***"We work actively with suppliers to ensure the materials we purchase are recyclable and sourced sustainably." (X008, RM052)***

Furthermore, firms co-developing circular solutions show a clear link between *Joint development of circular innovations (ks4)* and *Membership in circular networks (ks6)*, indicating that ecosystem participation supports innovation and knowledge sharing:

> ***"Collaboration with partners has been crucial. We wouldn't have achieved closed-loop material cycles without them." (X014, RC062)***

However, contradictions arose regarding operational barriers. The heatmap suggests a weaker-than-expected correlation between *Strategic collaboration with chain partners on circular packaging (ks7)* and *Customer co-development of circular initiatives (ks8)*, despite firms reporting significant challenges in closing logistical gaps:

> ***"We want to use secondary raw materials, but the logistics and storage of returned products remain a major hurdle." (X010, RM079)***

These insights highlight the importance of strengthening supplier engagement, ecosystem collaboration, and customer-driven innovation to enhance circular value chain performance.

Extension to the Finance Dimension Narrative

The qualitative findings emphasize that financial mechanisms play a pivotal role in advancing CE initiatives. A notable correlation was observed between *Investment in circular initiatives (f1)* and *Business cases for circularity (f2)*, confirming that firms securing financial backing for CE projects tend to establish clear economic justifications:

> ***"We had to build a strong financial case for circularity to secure board approval for long-term investments." (X013, RM042)***

Additionally, firms integrating circularity into their business models show a connection between *Circular revenue models (f3)* and emerging value streams, such as product-as-a-service:

> *"We shifted from one-time sales to product-as-a-service, creating recurring revenue from circularity." (X009, RC058)*

However, a contradiction arose regarding external funding. The heatmap indicates a weaker-than-expected correlation between *Access to circular economy financing (f5)* and actual financial stability, despite firms expressing reliance on external capital:

> *"We want to scale circular solutions, but securing CE-specific funding remains a major hurdle." (X010, RM067)*

These insights highlight the importance of robust financial planning, circular revenue models, and better access to targeted CE funding to drive long-term financial viability in circular transitions.

Extension to the Internal Operations Dimension Narrative

The qualitative findings highlight the increasing emphasis on efficiency and resource optimization within internal operations. A strong correlation exists between *Reduction of facility waste (ib1)* and *Efforts to recycle or reuse facility materials (ib2)*, confirming that firms focusing on efficiency also prioritize material recovery:

> *"We've implemented standardized procedures to reduce material waste and improve workflow efficiency." (X012, RM028)*

Additionally, firms are embedding sustainability into operational infrastructure, as reflected in the alignment between *Energy efficiency measures (ib3)* and *Use of sustainable energy sources (ib4)*:

> *"We've switched to solar energy and optimized systems to reduce overall consumption." (X010, RC036)*

However, a contradiction occurred regarding employee engagement. While the heatmap suggests a weaker link between *Employee incentives for circular behavior (ib5)* and actual operational outcomes, interviewees emphasize its importance:

> *"Employees are rewarded for suggesting improvements, and some of our best circular initiatives started that way." (X009, RM045)*

These insights suggest that while firms integrate energy efficiency and process optimization into internal operations, stronger emphasis on employee-driven innovation could further support circular performance.

Extension to the Environmental Dimension Narrative

The qualitative findings highlight the growing emphasis on measuring and reducing environmental impact. A strong correlation exists between *Emission reduction policies (m1)* and *Monitoring of* CO_2 *emissions (m2)*, confirming that firms implementing policies also ensure rigorous tracking:

> ***"We don't just set carbon targets; we measure them rigorously to track progress."*** *(X015, RM092)*

Additionally, firms improving circular water and energy use show alignment between *Water reuse systems (m11)* and *Environmental criteria for reducing energy consumption (m4)*:

> ***"Recycling wastewater has reduced our environmental footprint and cut costs."*** *(X009, RC059)*

However, contradictions emerged regarding material circularity. While the heatmap suggests a weak correlation between *Reduction of primary raw material use (m6)* and *Waste and rainwater reuse (m10)*, interviewees indicate logistical and regulatory barriers:

> ***"We aim for 100% recyclable inputs, but supply chain limitations slow us down."*** *(X012, RM075)*

These insights suggest that while firms prioritize emissions monitoring and resource efficiency, structural and supply-chain constraints hinder full circularity in material and waste management.

I Delphi Study

Introduction

The Delphi study is a technique employed to structure group communication processes. It involves a panel of experts tasked with evaluating the content of the developed artifact. This method is carried out through multiple rounds of questionnaires, which are moderated by a facilitator (Linstone & Turoff, 2002). The Delphi method was selected thanks to its ability to access and synthesize a wide array of expert opinions within a domain (Aysolmaz et al., 2020). Additionally, this method facilitates the early identification of current challenges, such as the comprehensibility of the MM (Hasson et al., 2000). It serves as a legitimate research approach, particularly valuable for addressing practical issues and when expert insight is required (McPherson et al., 2018).

Panel Selection

The Delphi technique involves identifying and selecting a panel of experts who possess knowledge of a firm's circular capabilities and CE performance. The model undergoes optimization over multiple iterative rounds. Critical factors in the selection of the panel are the experts' qualifications and the size of the panel (Powell, 2003):

- The ideal panel size is between 10 and 18 experts (Okoli & Pawlowski, 2004). However, due to time constraints with this research, the aim was to assemble between 8 and 10 experts.
- The experts do not face each other directly, to avoid bias.
- Panelists must be selected based on their experience and knowledge of the related domains (circularity, performance).
- Selected panelists should be contacted via email.
- It is important to have a heterogeneous group of experts regarding their backgrounds, to reduce single culture bias and provide diverse insights (Delbecq et al., 1975) (for example include academics, consultants, and industry experts)
- Conduct personal introduction meetings to ensure participants' engagement, explain the study's objectives and the expert panel's responsibilities.

Our Delphi study comprised three rounds, as additional rounds may lead to a reduced rate of convergence among expert opinions (Gallego & Bueno, 2014). The extent of agreement among the experts was assessed using Cronbach's Alpha (Bland & Altman, 1997). This coefficient ranges from 0 to 1, with a value of 0 indicating a complete lack of correlation among the experts' evaluations, whereas values approaching 1 signify a strong association. For the purpose of group comparisons, Cronbach's Alpha values exceeding 0.7 are deemed satisfactory (Bland & Altman, 1997). The subsequent sections elaborate on each Delphi round.

Round One

The panelists were five members of the CMT Research Team. Through a questionnaire distributed via Google Sheets, the experts evaluated each dimension and capability by selecting from three options: retain, modify, or eliminate. Participants who opted for either of the latter two options were required to provide a rationale for their decision. Furthermore, experts were invited to propose new dimensions and capabilities should they deem such additions valuable to the instrument, along with justifications. The academic literature does not furnish definitive guidelines for consensus determination (Powell, 2003); hence, it is posited that a strong majority vote to retain an element is necessary to establish consensus. Specifically, 80% of all experts must agree to 'retain' an element to ensure its inclusion in the model. Absent this level of agreement, the element would be subject to modification or elimination. During Delphi Round One, participants were presented with the dimensions and capabilities without including maturity levels. This initial round culminated in multiple outcomes including the rewording of items, the removal of certain capabilities, alterations to nomenclature, and the introduction of new items. Although changes to the dimensions occurred, they were minimal in nature.

Round Two

The panel comprised diverse academics, consultants, and industry experts. Members received a report detailing the initial model, along with a list of dimensions and capabilities that had been altered or omitted. Additionally, they received a report on the revised model, encompassing the newly integrated dimensions and capabilities, as well as the definitions of maturity levels. Within the context of an online questionnaire administered via Google Sheets, the experts were asked to select from three options for each dimension and capability: retain, modify, or eliminate. if they selected the latter two options, members were required to furnish justification for their decision. Furthermore, during the evaluation of round two, consensus was assessed using percentage agreement, with a predetermined threshold of 80% to determine the retention of elements. If this threshold was not met, the element underwent modification or was removed from the model.

Round Three

The third round served a confirmatory purpose, as a mechanism to collect information in order to either modify or remove certain elements from the model. Members were not specifically asked to introduce new model components. The primary objective was to validate the descriptions of the maturity levels, as well as the dimensions and items for the revised version. This confirmation process involved conveying the amended dimensions, item list, and maturity definitions from Round Two to the panel members in both Rounds One and Two. Members were asked to decide whether to retain, amend, or eliminate elements. After a thorough evaluation of all responses, the final iteration of the MM was constructed.

J Beta Test Item Refinement

Strategy

Table 36 displays the 8 items in the initial survey version. Based on the Delphi Rounds, the following item was added in the refined version:

- s9: Our organization's vision and mission embrace the principles of the circular economy.
- Finally: no items were deleted or changed during the Delphi rounds.

Communication

- Table 37 displays the 4 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:
- The wording of *c1* was changed to: *Our organization uses marketing to support customers' choice for circular products and services.*
- Item *c2* was deleted.
- Item *c3* no change
- The wording of *c4* was changed to: *We share relevant information with suppliers and customers to improve their circular performance.*
- New item added: *c5*: *We collect feedback from suppliers and customers to improve our circular performance.*

Skills

Table 38, displays the 7 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *v1, v3, v4, v6, v7* no change
- Items *v2 and v5* were deleted
- Item *v8* was added: *Our employees apply knowledge about the circular economy in their work.*

Leadership & Culture

Table 39 displays the 6 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *lc1, lc2, lc4, lc5* no change
- Item *lc3* was changed to: *Employees in our organization are engaged in initiatives that improve our circular performance.*
- Item *lc6* was changed to: *Management makes sufficient resources available for efforts in support of initiatives that contribute to our circular performance.*
- No items were added

Products & Services

Table 40 displays the 16 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *ps3, ps5* no change
- Items *ps1, ps6, ps8, ps10, ps11, ps13, ps14, ps16* were deleted
- Item *ps2* was changed to: *In our organization, renewable and secondary raw materials are used in the design of products.*
- Item *ps4* was changed to: *The products we design can be easily shared with other users, so that they can be used more intensively.*
- Item *ps7* was changed to: *Our organization uses or develops platforms that simplify the shared use of products and services.*
- Item *ps9* was changed to: *Our organization is taking action to use and make products smarter.*
- Item *ps12* was changed to: *Our organization takes action to extend the lifespan of products and components.*
- Item *ps15* was changed to: *Our organization takes action to put materials to good use at the end of their life cycle.*
- Item *ps17* was added: *As an organization, we take circularity into account when developing our services.*
- Item *ps18* was added: *Our organization contributes to circular customer choices through the offering of our services.*
- Item *ps19* was added: *Our turnover from services with a direct link to circularity has grown in recent years.*
- Item *ps20* was added: *Our organization reuses production waste in the production process.*

Innovation & Technology

Table 41 displays the 7 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *it3* no change
- Items *it2, it4, it6* were deleted
- Item *it1* was changed to: *No more primary raw materials are used in the production process.*
- Item *it5* was changed to: *Our organization has processes in place to use new technologies and research findings to develop circular products and services.*
- Item *it7* was changed to: *Our organization offers customers circular products and services that have unique advantages over competitors.*
- Item *it8* was added: *Our organization applies (digital) technology to use products, materials or machines more intensively.*

Value Chain Collaboration

Table 42 displays the 5 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *ks2, ks3* no change
- Items were deleted
- Item *ks1* was changed to: *When purchasing products and services, the supplying party(ies)' degree of circularity is taken into account.*
- Item *ks4* was changed to: *Together with other organisations we develop new circular solutions.*
- Item *ks5* was changed to: *The materials purchased are circular.*
- Item *ks6* was added: *Our organization is an active member of a network focused on the circular transition.*
- Item *ks7* was added: *Within our organization, we collaborate strategically with chain partners to achieve innovations that make the packaging process more circular.*
- Item *ks8* was added: *We enter into discussions with our customers to develop circular initiatives.*

Finance

Table 43 displays the 4 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- The name of the dimension was changed to *Business Model*
- Items *f3, f4* no change
- Item *f1* was changed to: *Our organization invests in initiatives that contribute to better circular performance.*
- Item *f2* was changed to: *Our organization creates business cases for initiatives that contribute to better circular performance.*
- Item *f5* was added: *Our organization knows how to attract the right financing for our circular business models.*

Internal Operations

Table 44 displays the 7 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- Items *ib1, ib2* no change
- Item *ib3* was changed to: *Within our organization, measures are being taken to reduce the energy consumption of internal business operations.*
- Item *ib4* was changed to: *In our organization we only use sustainable energy sources for the energy supply of internal business operations.*
- Item *ib5* was changed to: *In our organization, employees are rewarded for taking initiatives that improve the organization's circular business operations.*

- Item *ib6* was changed to: *In our organization we continuously work on reducing our employees' individual negative impact on climate.*
- Item *ib7* was changed to: *In our organization, circularity is a basic condition when purchasing (facility) materials.*
- Item *ib8* was added: *Our internal processes are designed to support the circular use of materials and products.*

Environmental

Table 45 displays the 12 items in the initial survey version. Based on the Delphi Rounds, the following applies for the refined version:

- The name of the dimension was changed to *Environmental Impact Data*
- Items *m1 m3, m4, m8, m9, m10, m11* were deleted
- Item *m2* was changed to: *In our organization we measure* CO_2 *emissions and other potential air-related emissions in order to reduce them.*
- Item *m5* was changed to: *In our organization we measure energy consumption in order to reduce it.*
- Item *m6* was changed to: *In our organization we measure the use of primary raw materials in order to reduce this.*
- Item *m7* was changed to: *In our organization we measure soil pollution in order to reduce this.*
- Item *m12* was changed to: *In our organization we measure water use and any water-related emissions in order to reduce them.*
- Item *m13* was added: *In our organization we monitor delivery risks.*
- Item *m14* was added: *In our organization we measure the impact of our business operations on biodiversity.*
- Item *m15* was added: *The environmental impact data within our organization is of good quality.*
- Item *m16* was added: *We calculate the environmental impact of our organization in a consistent manner to enable comparison.*
- Item *m17* was added: *People within our organization use environmental impact data analysis to make choices.*
- Item *m18* was added: *I have access to environmental impact data relevant to my work.*
- Item *m19* was added: *Insights from environmental impact data analyses are shared with other relevant firms.*
- Item *m20* was added: *Our organization measures material inflow and outflow.*

R-Strategies

Table 46 displays the 10 R-Strategies, derived from Potting et al. (2017). These outcome items remained unchanged in the refined version of the survey.

K Itempool Version 3

The following tables present the items for each respective dimension used in the Resource-Based View (RBV) study as described in Chapter 5. The items used for this study are part of Circular Maturity Tool (CMT) version 3. This version is the outcome of the Beta Test and within the scope of this research, is considered the final artifact. CE Performance, expressed through the R-Strategies, is exactly the same in the former version (2) as the outcome of the Alpha test. We therefore refer to Table 46, where the R-Strategies are described in detail.

Table 48: Strategic Capability Items

Code	Item
s1	Circularity is high on the CEO/director's agenda.
s2	There is a risk department within our organization that takes risks and opportunities into account when transitioning from linear to circular business operations.
s3	Our general strategy is aimed at becoming more circular.
s4	Our organization has measurable objectives with regard to circularity.
s5	Our circular reports are made public.
s6	Our organization has an implementation plan for circularity.
s7	Our organization influences laws and regulations with regard to the implementation of circular initiatives.
s8	Circular activities in our organization are certified.
s9	Our organization's vision and mission embrace the principles of the circular economy.
f1	Our organization invests in initiatives that contribute to better circular performance.
f2	Our organization creates business cases for initiatives that contribute to better circular performance.
f3	Circular revenue models have become the standard in our organization.
f4	The financial and sustainability administrations are integrated in our organization.
f5	Our organization knows how to attract the right financing for our circular business models.

Table 49: Marketing & Communication Capability Items

Code	Item
c1	Our organization uses marketing to support customers' choice for circular products and services.
c3	Within our organization, we actively communicate about circularity.
c4	We share relevant information with suppliers and customers to improve their circular performance.
c5	We collect feedback from suppliers and customers to improve our circular performance.

Table 50: People & Expertise Capability Items

Code	Item
v1	The employees in our organization have circular skills and knowledge.
v3	People in my organization want to increase their knowledge in the field of circularity.
v4	People in my organization are curious about circularity.
v6	Our organization has training programs to develop knowledge and skills regarding circular entrepreneurship.
v7	The aim to undertake circularity is supported by everyone in the organization.
v8	Our employees apply knowledge about the circular economy in their work.

Table 51: Leadership & Culture Dimension Capability Items

Code	Item
lc1	Employees in our organization feel supported if they have an innovative (circular) idea.
lc2	The ideas introduced about circularity are followed up within the organization.
lc3	Employees in our organization are engaged in initiatives that improve our circular performance.
lc4	The management is visibly and explicitly committed to circularity.
lc5	Within our organization, circularity is more important than maximizing profit.
lc6	Management makes sufficient resources available for efforts supporting initiatives that contribute to our circular performance.

Table 52: CE Products & Services Dimension Capability Items

Code	Item
ps2	In our organization, renewable and secondary raw materials are used in the design of products.
ps3	When designing products, our organization takes into account the moment when a product is no longer useful.
ps4	The products we design can be easily shared with other users, so that they can be used more intensively.
ps5	Our organization has implemented a process that structurally evaluates the life-cycle of products.
ps7	Our organization uses or develops platforms that simplify the shared use of products and services.
ps9	Our organization is taking action to use and make products smarter.
ps12	Our organization takes action to extend the lifespan of products and components.
ps15	Our organization takes action to put materials to good use at the end of their life cycle.
ps17	As an organization, we take circularity into account when developing our services.
ps18	Our organization contributes to circular customer choices through our service offering.
ps19	Our turnover from services with a direct link to circularity has grown in recent years.
ps20	Our organization reuses production waste in the production process.

Table 53: CE Innovation Capability Items

Code	Item
it1	Primary raw materials are no longer used in the production process.
it3	Our organization uses technology to extend the life of products.
it5	Our organization has processes in place to use new technologies and research findings to develop circular products and services.
it7	Our organization offers customers circular products and services that have unique advantages over competitors.
it8	Our organization applies (digital) technology to use products, materials or machines more intensively.

Table 54: Collaboration Capability Items

Code	Item
ks1	When purchasing products and services, the supplying party(ies)' degree of circularity is taken into account.
ks2	To enable circular entrepreneurship, we collaborate with other companies.
ks3	We encourage our suppliers to develop circular initiatives.
ks4	Together with other organisations we develop new circular solutions.
ks5	The materials purchased are circular.
ks6	Our organization is an active member of a network focused on the circular transition.
ks7	Within our organization, we collaborate strategically with chain partners to achieve innovations that make the packaging process more circular.
ks8	We enter into discussions with our customers to develop circular initiatives.

Table 55: Operational Capability Items

Code	Item
ib1	In our organization, we are constantly seeking to reduce the amount of facility waste.
ib2	Our organization is constantly considering ways to recycle or reuse facility materials.
ib3	Within our organization, measures are being taken to reduce the energy consumption of internal business operations.
ib4	In our organization we only use sustainable energy sources for the energy supply of internal business operations.
ib5	In our organization, employees are rewarded for taking initiatives that improve the organization's circular business operations.
ib6	In our organization we continuously work on reducing our employees' individual negative impact on climate.
ib7	In our organization, circularity is a basic condition when purchasing (facility) materials.
ib8	Our internal processes are designed to support the circular use of materials and products.

Table 56: Monitoring Capability Items

Code	Item
m2	In our organization we measure CO_2 emissions and other potential air-related emissions with the aim of reducing them.
m5	In our organization we measure energy consumption in order to reduce it.
m6	In our organization we measure the use of primary raw materials in order to reduce this.
m7	In our organization we measure soil pollution with a view to reducing it.
m12	In our organization we measure water use and any water-related emissions in order to reduce them.
m13	In our organization we monitor delivery risks.
m14	In our organization we measure the impact of our business operations on biodiversity.
m15	The environmental impact data within our organization is of good quality.
m16	We calculate the environmental impact of our organization in a consistent manner to enable comparison.
m17	People within our organization use environmental impact data analysis to make choices.
m18	I have access to environmental impact data relevant to my work. m19 Insights from environmental impact data analyses are shared with other relevant firms.
m20	Our organization measures material inflow and outflow.

L Online Appendices

The following materials are available online:

1. Body of Knowledge
2. VLW2025 Paper: *Samenwerken in de waardeketen als sleutel tot circulaire prestaties* (Dutch) – Presented at the Vervoerslogistieke Werkdagen 2025, Tegelen
3. Manuscript submitted to *Technovation* (under revision)
4. Code List – Overview of Category Codes and Sub Codes
5. Introduction Video: SLF Summit 2023 – *Towards Green and Resilient Service Supply Chains*
6. EurOMA Sustainability Forum 2024 – Extended Abstract (Hamburg)
7. EurOMA Sustainability Forum 2024 – Presentation (Hamburg)
8. Dimensions overview and Clustering (xls)
9. Artifact Promotion Video (in Dutch)
10. Artifact Promotion Video (Dutch with English subtitles)
11. Research Poster (Dutch)
12. Research Paper – Preliminary version (v0.5), presented at SLF Conference
13. Poster: Circular Maturity Model – Preliminary version (v0.5), presented at SLF Conference
14. Cleaned Beta Test Survey Dataset (v2) (XLS)
15. Interview Overview
16. Cleaned Validation Survey Dataset (v3) (XLS)
17. Curriculum Vitae Arjen A.C.M. Wierikx

The additional appendices can be accessed by scanning the adjacent QR-code or visiting: https://edu.nl/3pytb

M Supporting Organizations

Table 57 lists the organizations and representatives who formally expressed their support for this PhD research through an endorsement letter.

Table 57: Supporting Organizations and their Representatives

Organization	Contact Person	Position
Aalberts Industries	Robert Stouwdam	Business Unit Director
Aebi Schmidt	Joost Sterenborg	Head GroupSolution Development
Aeronamic	Steffen de Vries	CEO
Alliance Automotive Group	Peter Meyer	Supply Chain Director Europe
ASML	Tim van Rens	Business Manager Reuse
Brabant Development Agency	Roland Grimm	Program Manager
evofenedex	Machiel van der Kuijl	Managing Director
GS1	Loek Boortman	CTO
IT Circle Netherlands	Karen van der Zanden	Director
Philips	Kurtuluş Barış Öner	Parts Lifecycle Leader
Service Logistics Forum	Ben Gräve	Chairman
Stichting Transactieland	Nanko Boerma	Chairman / Director
TKI-Dinalog	Albert Veenstra	Scientific Director Chairman
Topsector Logistiek	Aad Veenman	Chairman
Association for Logistics Management	Peter Oosterbeek	Chairman

N Project Overview

The first column of the table below lists the years when the projects were executed. For some projects, the project number and version of the Circular Maturity Tool (CMT) version are included in brackets.

Table 58: Overview of Empirical Projects Conducted During the PhD Research

Year	Title, Purpose and Activities	Partner(s)
2019	**LoCiBel** Longitudinal Study of Circular Business Models in Logistics. Exploratory interviews and system mapping to understand required phases to set up longitudinal study and information center.	Hogeschool Utrecht, NHL Stenden.
2020–2022	**CBMM** Circular Business Model Maturation in Logistics. Research in 4 workpackages focused on identifying opportunities to migrate to a more circular business model.	HU, NHL Stenden, WUR, TU/e, Area Cleaning, ASML, Drake & Farrell, Oost NL, Transactieland, Milling Company Europe, Aebi Schmidt, Philips, Service Logistics Forum
2020–2021	**HU PhD Voucher Application** Developing Research proposal to apply for a PhD research voucher enabling financing my PhD research for 3 days /week for 4 years. The voucher was granted in Juni 2021, PhD research officially started September 2021.	HU, TU/e and application support by: Aeronamic, Alliance Automotive Group, ASML, BOM, TKI Dinalog, evofenedex, GS1, IT Circle Netherlands, Philips, SLF, Stichting Transactieland, Topsector Logistiek, VLM.
2021–2022 (2201)	**Exploratory Interviews** Collecting qualitative data using semi structured exploratory interviews (13) on measuring circular performance, the role of digital technology strategies and the challenges and opportunities to migrate to circular business models.	Alliance Automotive, Morssinkhof, Philips, Aebi Schmidt, Castlab, Aeronamic, KPMG, Corporate Fashion Industries, ASML, Vanenburg Group, LC Packaging, Circular IT Group, Utrecht University
2021–2022 (1601)	**Initial Interviews Route Circulair** Converting interview data from semi-structured interviews (23) previously conducted by Route Circulair, into codable transcripts.	Ahrend & Gispen, Auping, Closing the Loop, Desko, DSM, Finch, Gerrard Street, Greenwheels, Gryproc, HVC, Interface, Ioniqa, NS, Peerby, Philips, Rockwool, Vinted, Van de Sant.

Table 58: Overview of Empirical Projects Conducted During the PhD Research – Continued

Year	Title, Purpose and Activities	Partner(s)
2022–2023 (2202)	**Follow up Interviews Route Circulair** Converting interview data from conducted semistructured follow up interviews (14) by Route Circulair into codable transcripts. In the follow up (semi structured) interviews, more emphasis was placed on value chain collaboration and business model migration.	Delta Development Group, Finch, Van de Sant, Closing the Loop, DSM, Gerrard Street, Coolrec, Auping, Interface, HVC, Ahrend & Gispen, Roompot, Hutten Catering, Rijksoverheid.
2021–2022	**Systematic Literature Review** Systematic literature review (SLR) of circular economy maturity models and measuring circular performance, focusing on structure, application, and theoretical foundations.	Deskresearch
2022 (v0.5) (2301) (2302) (2303)	**Building and Testing Preliminary Artifact** Using the SLR results, the qualitative data from the interviews and additional qualitative data from 4 interviews to create an preliminary version of the artifact. The preliminary version was developed and tested in cooperation with 3 Junior Researchers from Business and IT Management (BIM). The work was presented at the Service Logistics Forum conference (see Table 33 and Appendix L #12 and #13).	Route Circulair, Astrid van den Berg, Brent Rietveld, Jop de Winter, Service Logistics Forum, Ouwehand, Beelen, Servilocker.
2022–2023 (v1)	**Building and Testing the Alpha Version** Based on the available qualitative data, the SLR data and the findings from the preliminary version, we created the Alpha Version of the Artifact. The Alpha Version was tested by a group of Experts.	Main Research Team, Route Circulair and Experts: Antoine Heideveld (Groene Brein), Greg Bruininkx (Province of Utrecht), Rolf Gelpke (Dutch Railways), Dijs Punt (Province of Utrecht), Maartje Bodde (Municipality of Utrecht), Helen Toxopeus (Utrecht University).
2023 (v2)	**Creating the Beta Version** The results from Testing the Alpha Version were evaluated by the Research Team. Ultimately the Beta Version was created, including an online survey developed using Typeform (see Appendix O).	Route Circulair, Research Team Utrecht University of Applied Sciences and Eindhoven University of Technology.

Table 58: Overview of Empirical Projects Conducted During the PhD Research – Continued

Year	Title, Purpose and Activities	Partner(s)
2023 (v2) (2304)	**Province of Utrecht** On May 8, 2023 the Beta Version was officially launched in a project in collaboration with the Province of Utrecht. The project's goals were to a) collect empirical data based on survey completions and b) perform additional case studies in conjunction with survey completions to gain more in depth information on how the dimensions and items were received. By the end of the project, a significant number of surveys was returned in full and 10 additional interviews + workshops were conducted at 7 different firms.	Collaboration with Province of Utrecht and case studies at: Van Straten Medical, Studio Wae, Aalberts Industries, Meander MC, Brass, Havi and TSN Groen. Firms that only completed the survey are not mentioned explicitly.
2023 (v2) (2306)	**Timpaan** The Beta Version of the Artifact was used in a case study with Timpaan, resulting in quantitative survey data and 3 additional interviews.	Route Circulair and Timpaan.
2023–2024 (v2) (2307) (2401)	**Amsterdam and Alphen a/d Rijn** Similar to the Province of Utrecht project, a project was conducted for the municipalities of Alphen a/d Rijn (2307) and Amsterdam (2401). Apart from suvey data (56), complementary semi structured interviews (18) were conducted to collect qualitative data from 5 firms in Amsterdam.	Collaboration with the municipalities of Alphen a/d Rijn and Amsterdam and case studies at: Bakkers Brigade, Brouwerij 't IJ, Kesbeke, Mr. Marvis and Hifi Klubben.
2024 (v2) (2402)	**Horsman & Co.** The Beta Version of the Artifact was used in a case study with Horsman & Co., resulting in quantitative survey data and 5 additional interviews.	Route Circulair and Horsman & Co.
2024 (v2)	**Delphi** Deployment of the Beta Version resulted in close to 150 usable survey completions and 36 additional interviews from 14 firms for transcription and coding leading to the next DS cycle. Finally dimensions and items were evaluated through three Delphi Rounds.	Route Circulair and Delphi experts: Anne van Bruggen (RIVM), Inge Oskam (HvA), Pasal Sluiter(HU), Greg Bruininkx (Provincie Utrecht), Pascal Ravesteijn (HU), Leon van Ast (Circulair West), Carolien van Beek (Lely), Ton van Kollenburg (HR), Dennis Vegter (NHL Stenden).

Table 58: Overview of Empirical Projects Conducted During the PhD Research – Continued

Year	Title, Purpose and Activities	Partner(s)
2024 (v3)	**Final Artifact creation** The survey data, the transcribed and coded interviews and the results of the Delphi rounds were used to compile the final artifact: the CMT. In order to prepare for general availability, the Typeform platform was changed to a Qualtrics platform (see Appendix O). The final artifact (v3) was launched on March 12, 2024 (see Table 33).	Route Circulair and Junior Researchers: Niels Rijnders, Ruben Pater and Xander Groenewoud for co-coding interviews.
2024–now (v3)	**General Data Collection** The CMT is available now and free to use (link: CMT). It is available in Dutch and in English. The original Dutch version was translated in May 2024 by a native English speaker.	Route Circulair
2024 (v3)	**High Tech Case Study** In depth case study with high tech firms using CMT. Additional interviews and survey data (interview data not used in this PhD research).	Province of Noord Brabant, Route Circulair and ImpactX
2023–2024 (v2+v3 data)	**SEM PLS validation** A complementary subset of the version 2 (Beta Version) and version 3 (Final Artifact) dataset were used to study the validation of the various constructs.	Research Team HU and TU/e
2025 (v3) (2501)	**Thetford** Additional interviews and survey data (data not used in PhD research).	Route Circulair & Thetford

O Overview of Software Used

During the course of my PhD research, I used a range of software tools to support various aspects of the work, including data analysis, writing, and presentation. The table below is an overview of the main tools I used, including the versions and primary applications.

Table 59: Overview of Software Used

Software Name	Version	Purpose/Usage
Amberscript	Online platform	Transcribing interviews and spoken content to facilitate qualitative data analysis
ATLAS.ti	24.2.1 (32295)	Conducting qualitative data analysis through coding, categorization, and thematic exploration of interview transcripts and documents
CamperContact	Mobile app	Finding suitable motorhome locations for both relaxation and focused dissertation work
ChatGPT	Online platform	Research and LaTeX support
Connected Papers	Online platform	Exploring related academic literature and visualizing research paper networks to support literature review
Dimensions	Online platform	Searching for and analyzing academic publications, citations, and research metrics to support literature review and research positioning
G*Power	3.1.9.7	Conducting statistical power analyses to determine appropriate sample sizes and assess the sensitivity of quantitative tests
Google Docs	Online platform	Writing memos and notes etc.
Google Meet	Online platform	Online meetings
Google Scholar	Online platform	Searching for and accessing academic literature
Google Sheets	Online platform	Managing data and administering interviews collaboratively through cloud-based spreadsheets
Google Translate	Online platform	Initial translations
Grammarly	Browser extension	Supporting clear and correct English writing through grammar and style suggestions
HTTP	Online platform	HTTP Program the CMT results platform
HUGO	Online platform	Searching academic resources for literature via the Hogeschool Utrecht library system (HUGO)

Table 59: Overview of Software Used – Continued

Software Name	Version	Purpose/Usage
iThenticate	Online platform	Checking for potential plagiarism to ensure originality and academic integrity
ReadCube Papers	5.2.4	Managing academic references and organizing literature for efficient access and citation
Komoot	Mobile app	Taking breaks from PhD research and supporting relaxation through outdoor activities
LinkedIn	Online platform	Documenting professional development and engaging with academic and professional networks
Lucidchart	Online platform	Creating diagrams and visual models
Mentimeter	Online platform	Collecting input
Microsoft Excel	365	Managing data and performing calculations for organizing research inputs and supporting analysis
Microsoft Outlook	365	E-mail
Microsoft PowerPoint	365	Presentations
Microsoft Teams	365	Online meetings
Microsoft Word	365	Preparing small documents
MindMeister	Online platform	Creating mind maps to structure ideas and explore conceptual relationships
Obsidian	1.8.10	Organizing research notes and connecting ideas using a markdown-based, linked note-taking system
ORCID	Online platform	Maintaining a persistent digital identifier to distinguish authorship and link research outputs to a personal academic profile
OSF (Open Science Framework)	Online platform	Archiving, organizing, and publicly sharing research materials and data related to this dissertation
Overleaf	Online platform	Writing papers, this dissertation and Body of Knowledge (in LaTeX)
Parallels	19.1	Running Windows-based research software on a Mac system to ensure compatibility and access to necessary tools

Table 59: Overview of Software Used – Continued

Software Name	Version	Purpose/Usage
Qualtrics	Online platform	Commencing the collection of survey data at the culmination of the final artifact
Research Drive	5.05	Datastorage (and management)
ResearchGate	Online platform	Accessing academic publications, engaging with researchers, and following developments in relevant research fields
Scopus	Online platform	Searching peer-reviewed literature and analyzing citation data to support the literature review and research context
SmartPLS	4.1.0.9	Conducting structural equation modeling (SEM) for the analysis of complex relationships between latent variables
Typeform	Online platform	Collecting survey data up to the beta testing phase
Web of Science	Online platform	Conducting comprehensive literature searches and citation analyses to inform the research framework and identify influential publications
WorldCat Discovery (TU/e)	Online platform	Accessing academic literature and library resources via the Eindhoven University of Technology (TU/e) discovery system
Writefull	2025.49.0	Improving academic writing by checking grammar, style, and consistency in English texts
SmartPLS	4.1.0.9	Conducting structural equation modeling (SEM) for the analysis of complex relationships between latent variables
Typeform	Online platform	Collecting survey data up to the beta testing phase
Web of Science	Online platform	Conducting comprehensive literature searches and citation analyses to inform the research framework and identify influential publications
WorldCat Discovery (TU/e)	Online platform	Accessing academic literature and library resources via the Eindhoven University of Technology (TU/e) discovery system
Writefull	2025.49.0	Improving academic writing by checking grammar, style, and consistency in English texts

Epilogue
Summary
Samenvatting
About the Author

Epilogue

The completion of this dissertation marks the conclusion of a long and deeply personal journey that began over thirty years ago in conversations with Professor Kees Ruijgrok at TNO. A journey that has brought laughter, inspiration, frustration, anger, creativity, and the many things I learned along the way. Throughout all the hours spent on this project, one question has remained central: When I look in the mirror, can I still say I was doing this because I genuinely enjoyed it? The answer is yes, absolutely. Of course there were moments when I wanted to throw in the towel. However, thanks to the support of the people around me, I was always able to take a step back: "relax, reflect, and recharge" then move on. Completing my PhD stands as proof to myself, that I possess the perseverance, resilience, tenacity, and determination to dive into the nitty-gritty details, face them head-on, and ultimately succeed.

Looking back, the career switch I made in 2020, after twenty years of entrepreneurship, was profound. As described in the prologue, it marked a return to research and education, and set the stage for this entire experience.

There were times when progress felt less like the result of deliberate planning, and more like a subtle unfolding, an alignment of people, questions, and insights that emerged at precisely the right time. These moments defied linear explanation, yet they carried meaning, direction, and momentum. They reminded me, once again, of the concept of synchronicity, as described by Joe Jaworski and introduced in the prologue, where deep commitment seems to invite unforeseen and purposeful connections (Jaworski, 2011).

Reflecting on these experiences, I realize how naturally this idea of synchronicity resonates with a constructivist worldview. In that paradigm, knowledge is not simply discovered; it is co-created through relationship, context, and interpretation. Meaningful breakthroughs often come not from control or measurement alone, but from being attuned to the subtleties of context, the tacit patterns in conversation, and the intuition that something matters, even before you can explain why.

Viewed through a neo-positivist lens, such moments might be considered anecdotal or methodologically suspect, insufficiently rigorous or replicable. But from a constructivist perspective, they are neither incidental nor irrelevant. They are part of how insight actually emerges in complex, real-world settings: messy, unpredictable, and yet deeply instructive.

This dissertation has taught me that doing research is not only a technical exercise; it is also a relational, intuitive, and sometimes even synchronistic process. It requires rigor, yes, but also receptivity. And it is in the balance between those qualities that truly meaningful knowledge can arise, both in science, and in life.

Summary

This dissertation explores how firms can systematically measure and improve their CE Performance through the development and validation of the Circular Maturity Tool (CMT). Framed within sustainability transitions and circular economy research, the study adopts a Design Science (DS) approach combined with Maturity Model (MM) development to deliver a validated, practitioner-oriented assessment tool.

Research Context and Motivation

The Circular Economy (CE) offers a compelling response to environmental and resource challenges by promoting closed-loop systems, resource efficiency, and regenerative design. While CE principles are widely endorsed, many firms struggle to translate them into actionable strategies. A key obstacle is the lack of standardized and empirically validated tools to assess circular capabilities and structure the transition process.

To address this gap, the central research question asks: *How can firms systematically assess and develop their circular capabilities to advance circular maturity using a standardized artifact?* This dissertation positions the CMT as a strategic solution that connects academic insights with managerial needs, enabling firms to assess, benchmark, and progress their circular transition.

Research Design and Methodology

The study follows a structured six-phase DS methodology (problem identification, objective definition, design, demonstration, evaluation, and communication) mapped onto maturity model development stages. The Design Science Validity Framework (DSVF) is applied throughout, assessing criterion, causal, and contextual validity. Empirical grounding combines literature review, qualitative interviews, surveys, and statistical testing. Alpha and beta testing phases evaluate the tool's usability and validity across diverse firms and sectors. Delphi rounds with CE experts strengthen construct validity and relevance. This mixed-method, iterative approach ensures both conceptual rigor and field-tested applicability.

Key Contributions

Theoretical Contributions

The CMT advances the conceptualization of circular maturity by integrating 10 inter-dependent dimensions: *Strategy, Business Model, Products & Services, Innovation & Technology, Value Chain Collaboration, Leadership & Culture, Skills, Communication, Internal Operations, and Environmental Impact Data* into a cohesive framework. It provides a system-level view of CE Performance, guiding firms from fragmented efforts to transformative integration.

The dissertation contributes to the circular transition literature by operationalizing CE capabilities into a measurable structure, emphasizing interdependencies between dimensions and the role of organizational learning and culture in enabling systemic change.

Methodological Contributions

The research demonstrates the effectiveness of combining DS and MM development to create validated tools with both scientific and practical value. It introduces beta testing as a distinct phase within DS, offering insights into real-world application and iterative refinement.
It also applies the DSVF in a novel context, adding methodological depth to artifact validation. The triangulated use of interviews, heatmaps, item-level statistical analyses, and Delphi input exemplifies methodological pluralism within sustainability research.

Practical Contributions

For practitioners, the CMT provides a diagnostic and strategic tool for evaluating circular readiness, identifying improvement areas, and benchmarking progress. Its maturity logic supports phased transition planning and alignment with regulatory and market expectations. The tool has been tested in a wide range of organizations, supporting organizational learning and performance improvement. The modular structure allows firms at various CE maturity levels to engage with it meaningfully and adaptively.

Structure of the Dissertation

The dissertation is structured into six chapters. Chapter 1 introduces the research motivation and objectives. Chapter 2 outlines the integrated DS and MM research design. Chapter 3 describes the conceptual development of the CMT. Chapter 4 details empirical validation through testing and statistical analysis. Chapter 5 extends validation by incorporating theory-informed narrative analyses of circular capabilities. Chapter 6 synthesizes findings, discusses implications, and outlines future research directions.

Concluding Remarks

By bridging academic research and practical application, this dissertation provides a validated, scalable tool to support firms while they navigate their CE transition. The CMT helps embed CE into core strategy, operations, and culture, while contributing to scholarly discourse on sustainable transformation and design-oriented research. The work reinforces the value of interdisciplinary collaboration and artifact-based inquiry in addressing complex sustainability challenges, and offers a foundation for future CE measurement and capability development efforts.

Samenvatting / Dutch summary

In dit proefschrift wordt onderzocht hoe bedrijven op een systematische manier hun prestaties op het gebied van de circulaire economie (CE) kunnen meten én verbeteren. Dit gebeurt aan de hand van de ontwikkeling en validatie van het Circular Maturity Tool (CMT) (de Circulaire Volwassenheidsmeting). De studie is ingebed in onderzoek naar duurzaamheidstransities en circulaire economie en combineert Design Science (DS) met volwassenheidsmodellen (MM) ontwikkeling om tot een praktijkgericht en wetenschappelijk onderbouwd meetinstrument te komen.

Achtergrond en Motivatie

De circulaire economie biedt een aantrekkelijk antwoord op milieuproblemen en grondstofschaarste, door onder andere in te zetten op hergebruik, efficiënt gebruik van materialen en slim productontwerp. Veel bedrijven willen hiermee aan de slag, maar weten niet goed hoe. Er is namelijk nog geen standaard en goed getest hulpmiddel dat bedrijven helpt hun circulaire capaciteiten in kaart te brengen en te verbeteren.

Daarom staat in dit onderzoek de vraag centraal: *Hoe kunnen bedrijven hun circulaire capaciteiten systematisch beoordelen en ontwikkelen om hun circulaire volwassenheid te vergroten met behulp van een gestandaardiseerd hulpmiddel?* De CMT wordt in dit proefschrift gepresenteerd als zo'n hulpmiddel dat wetenschappelijke inzichten koppelt aan de praktijk, zodat bedrijven gericht kunnen werken aan hun circulaire transitie.

Onderzoeksopzet en Methodologie

Het onderzoek bestaat uit zes fasen volgens de DS-methode: probleemidentificatie, doelbepaling, ontwerp, demonstratie, evaluatie en communicatie. Deze fases zijn gekoppeld aan stappen voor het ontwikkelen van een volwassenheidsmodel.
De validiteit van het model wordt getest met behulp van het Design Science Validity Framework (DSVF), waarbij gekeken wordt naar drie vormen van validiteit: criterium-, oorzaak- en contextvaliditeit.

Voor het onderzoek zijn verder verschillende aanvullende methodes gebruikt: literatuurstudie, interviews, enquêtes en statistische analyses. Het model is getest in alfa-en betafases, waarbij het is toegepast in diverse organisaties. Ook zijn er Delphi-sessies gehouden met experts om het model verder te verfijnen. Deze aanpak zorgt ervoor dat het model zowel wetenschappelijk betrouwbaar als praktisch toepasbaar is.

Belangrijkste Bijdragen

Theoretische Bijdragen

Het CMT biedt een nieuwe manier om naar circulaire volwassenheid te kijken. Het model bestaat uit 10 samenhangende dimensies: *Strategie, Businessmodel, Producten & Diensten, Innovatie & Technologie, Waardeketen-samenwerking, Leiderschap & Cultuur, Vaardigheden, Communicatie, Interne Processen, en Milieu-impactdata.* Dit biedt een totaalbeeld van waar een organisatie staat en hoe zij zich kan ontwikkelen richting een meer circulaire werkwijze.

Ook draagt het onderzoek bij aan de literatuur over duurzame transities, door circulaire capaciteiten meetbaar te maken en de rol van leren en cultuur in de transitie te benadrukken.

Methodologische Bijdragen

Het onderzoek laat zien dat het combineren van DS en MMs goed werkt bij het ontwikkelen van praktische tools met wetenschappelijke waarde. Betatesting wordt als aparte fase toegevoegd aan het proces, wat zorgt voor waardevolle feedback uit de praktijk.

Daarnaast wordt het DSVF-model op een vernieuwende manier toegepast om het ontwerp te toetsen. Door interviews, heatmaps, statistiek en expertpanels te combineren, wordt een breed en diepgaand beeld verkregen.

Praktische Bijdragen

Voor organisaties is het CMT een hulpmiddel om te bepalen hoe ver ze zijn met circulariteit, waar nog verbetering nodig is, en hoe ze zich verhouden tot andere bedrijven. De verschillende niveaus in het model bieden een stappenplan voor een geleidelijke transitie. Het model is getest in vele organisaties en heeft geleid tot bruikbare inzichten en leerprocessen. Dankzij de modulaire opbouw is het geschikt voor zowel beginners als gevorderde organisaties op het gebied van CE.

Opbouw van het Proefschrift

Het proefschrift bestaat uit zes hoofdstukken. Hoofdstuk 1 introduceert het probleem, de motivatie en de doelen. Hoofdstuk 2 beschrijft de onderzoeksopzet met DS en MM. Hoofdstuk 3 gaat in op de conceptuele ontwikkeling van het model. Hoofdstuk 4 beschrijft de empirische validatie via tests en analyses. Hoofdstuk 5 voegt aanvullende inzichten toe via narratieve analyses van circulaire capaciteiten. Hoofdstuk 6 sluit af met een samenvatting, implicaties en suggesties voor vervolgonderzoek.

Slotopmerkingen

Door wetenschappelijke diepgang te combineren met praktische bruikbaarheid, biedt dit proefschrift een gevalideerd en schaalbaar hulpmiddel voor organisaties die werk willen maken van circulariteit. De CMT helpt om CE een plek te geven in strategie, operatie en cultuur, en draagt bij aan wetenschappelijke discussies over duurzaamheid en ontwerpgericht onderzoek.

Het onderzoek onderstreept het belang van samenwerking tussen disciplines en van praktische ontwerpen in het aanpakken van complexe duurzaamheidsvraagstukken. Daarmee vormt het een stevige basis voor toekomstig onderzoek naar CE-metingen en capaciteitsontwikkeling.

About the Author

Arjen Wierikx (1966) is an experienced transformation consultant, executive coach, and implementation manager, with a strong background in both engineering and organizational change. He holds a MSc in Civil Engineering from Delft University of Technology and has pursued various post-graduate programs in leadership, systemic work, and business strategy at institutions such as Nyenrode Business University, the Bert Hellinger Institute, and Phoenix Opleidingen.

With over 30 years experience, Arjen has supported organizations across sectors, including logistics, manufacturing, government, and IT, in implementing strategic transitions, digital transformations, and large-scale change programs. His work combines technical expertise with a deep understanding of human systems, helping executives and teams align strategy and execution.

In addition to his consulting and coaching work, Arjen has held leadership roles at Baan Company and contributed to several public-sector initiatives, including advisory work for the United Nations Development Programme. He founded Mondea and served as its managing partner for 20 years. He is known for his practical mindset, systemic thinking, and ability to connect people and opportunities.

Beyond his professional pursuits, Arjen lives in Amersfoort, the Netherlands, with his wife Marjolein. Together, they have raised five children in a lively and loving family. In his free time, Arjen enjoys exploring nature with his camper 'Red Ruby Runaway,' hiking, swimming in open (often cold) water, running, and gravel biking. He also treasures cooking on the Kamado Joe, good food in general, a fine glass of wine or whisky, and spending quality time with family and friends.

This dissertation reflects his long-standing interest in the intersection of circularity, organizational transformation, and system innovation. It contributes to both an academic and a practical understanding of how firms can transition to circular economy models.

A full version of the Curriculum Vitae is available via the Online Appendices (see Appendix L #17).

Explanation of the images

On the pathway toward circular system change, we begin by examining existing systems. How do they function today? What can we learn from them? What should we leave behind, and what should we carry forward?

Systems in both nature and technology reveal themselves when we zoom in, but also when we step back and observe from a distance. As a researcher, I have taken the same approach: exploring dynamics from a systems perspective, while also exploring what unfolds within firms at the micro level.

In the visuals, these 'systems' come to life through a combination of zoomed-in and zoomed-out perspectives, drawing from both natural and technological contexts.

In a world where economic growth collides with planetary limits, organizations struggle to become truly circular.

This dissertation addresses this challenge by developing and validating a **Circular Maturity Tool for firms** through a rigorous, iterative design science approach. It reveals the capabilities firms need to make circularity work, and how they can systematically build them. Grounded in extensive empirical research, including over 3,000 assessments and more than 100 interviews, it bridges science and practice to offer a clear, actionable roadmap from ambition to measurable impact.

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