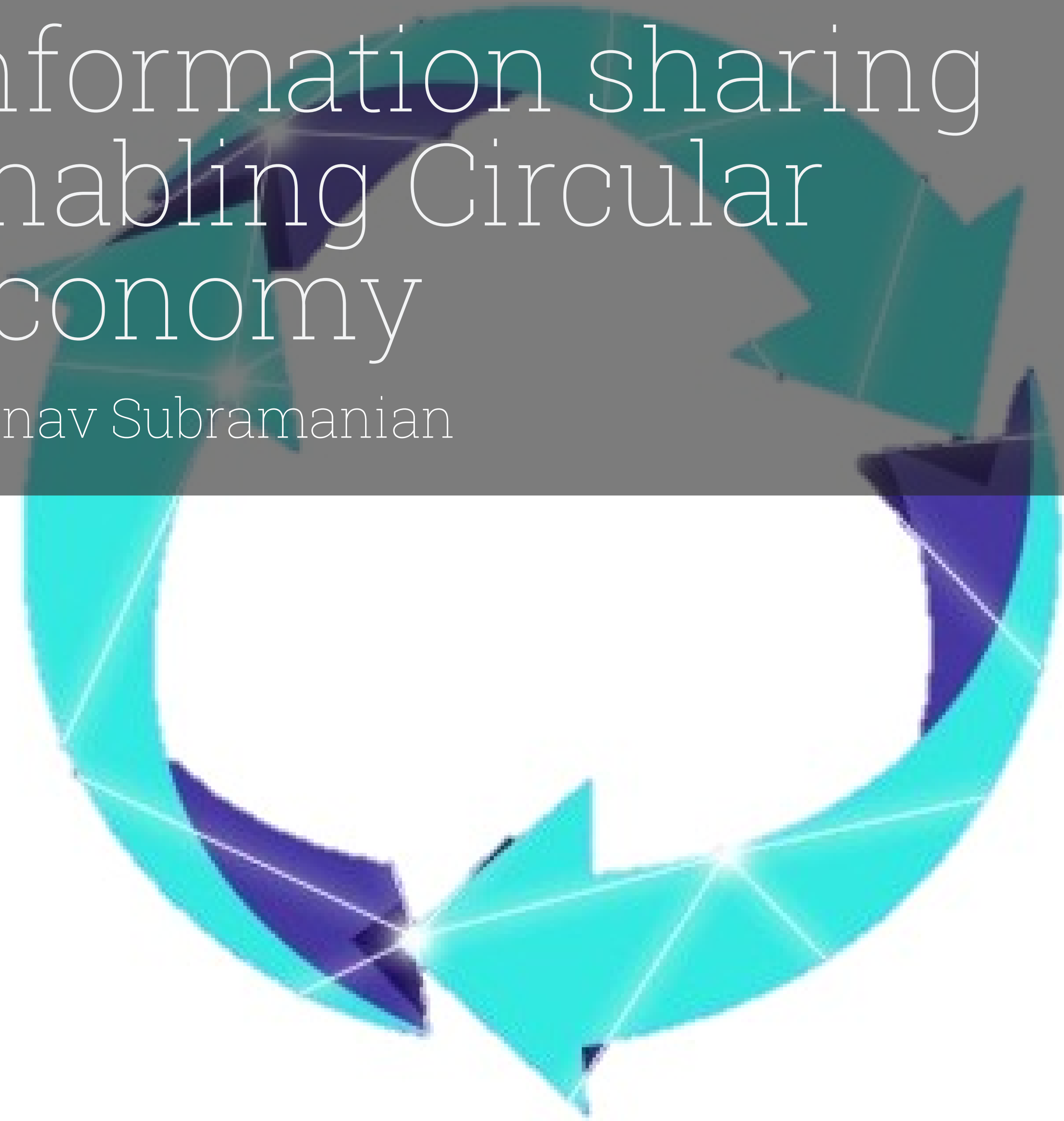
Context-aware information sharing enabling Circular Economy

Pranav Subramanian



Context-aware information sharing enabling Circular Economy

by

Pranav Subramanian

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Preface

Two years ago, I made one of the most significant and difficult decisions to leave my family, friends, and country to pursue a master's degree in an entirely new country and environment. This decision was supported by my parents and friends, who supported me in taking part in this incredible journey that was filled with both hardships and exciting moments. As I continued my education journey from school to bachelor's and now to my master's, I finally parted ways from academic life and moved to the years of professional life.

Throughout this journey, I was fortunate to have the constant guidance and support of my graduation committee. I would like to start by thanking Jolien Ubacht, who is my chair and my first supervisor in the committee. Her insightful feedback and constant support helped me push my thesis and myself. I would also like to thank Dimitris Xevgenos, my second Supervisor, who introduced me to so many people by inviting me to conferences and connecting me to companies. I would like to thank the entire committee for always giving me the freedom and the feedback provided during the various meetings, which aided in creating a cohesive research project. At last, I would like to thank all the participants who took part in the interview for my thesis.

I am immensely grateful to my family who have supported me every step of the way. Your constant support, patience, and love have been my greatest strength throughout this remarkable journey. Finally, a big thanks to the friends who are present here and also the ones around the world who were constantly supporting me, regardless of their schedules.

Looking back at this journey, I am very happy about this journey and I am convinced that taking this decision was the right step for both my professional and personal growth. Despite numerous ups and downs, this experience has provided me not just with knowledge but a lot of connections that I value.

Pranav Subramanian
Delft, August2025

Executive Summary

Small and medium-sized enterprises (SME) across Europe face increasing pressure to adopt digital information-sharing tools to enable circular economy (CE) transitions. However, there is a lack of tailored frameworks to help and support SMEs assess which digital technologies best fit their specific operational and sectoral contexts. This research addresses that gap by developing a conceptual framework that can guide SMEs in identifying the appropriate information-sharing system based on the contextual factors.

The core research question is: *Which conceptual framework shows the relationship between context-based factors and information-sharing systems for circular business activities by SMEs?*

Adopting a Design Science Research (DSR) methodology, the study progressed through main phases - the problem identification phase to identify the various information-sharing systems (Chapter 3), analysis of contextual factors (Chapter 4), development of a mapping framework based on low-medium-high (LMH) ratings (Chapter 5), and finally validation through expert interviews and real-world EU project walkthroughs (Chapter 6). A structured literature review informed the identification of numerous digital tool types, clustered into six archetypes. Eleven contextual factors were derived from the literature, representing regulatory, organizational, and technological domains.

The resulting conceptual framework provides a structured mapping between contextual factors and information-sharing systems using a qualitative LMH scoring logic. This mapping supports SMEs in making informed decisions based on their specific characteristics. Validation was conducted through an SME interview and two EU Horizon 2020 case walkthroughs (CircThread and Project Ô), which demonstrated the applicability and limitations of the framework. Initial interview suggested a more usable clustering of the 11 contextual factors into five themes (market, product, legal, team, financial), laying the groundwork for future operationalization.

This research contributes to the literature by bridging fragmented discussions on CE digitalization and contextual variability, offering a practical and design-based approach for SMEs. It also extends the use of DSR in CE policy and SME digitalization by demonstrating how the conceptual insights can be translated into actionable frameworks. The study highlights the role of contextual factors in shaping technology choice, beyond one-size-fits-all models that are common in digital transition literature.

The framework could offer SMEs a structured starting point for evaluating the ideal information-sharing system for their circular economy goals, with potential to evolve into a self-assessment or advisory tool in future iterations. Limitations include reliance on literature-derived ratings, limited empirical validation. Future research should focus on expanding empirical grounding, refining SME self-assessment mechanisms, and exploring how contextual factor clusters can be implemented in practical tool kits.

In conclusion, the study provides a novel framework that supports SMEs navigating CE digitalization decisions. It demonstrates that technology alignment is not only a matter of availability, but a fit that is shaped by regulatory, organizational, and other such contextual conditions.

Keywords - circular economy, information-sharing systems, SMEs, design science research, contextual factors.

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1 Introduction

The rising urgency of environmental, social, and economic crises has cast an unflinching spotlight on the inadequacies of the traditional linear "take–make–use–dispose" economic model. Over the last two decades, studies have documented the accelerating depletion of virgin resources, widespread landfilling of valuable materials, and pervasive ecosystem degradation-outcomes born of a system predicated on assumptions of infinite inputs and low-cost waste disposal (Abu-Ghunmi et al., 2016; Findik et al., 2023; GarcíaQuevedo et al., 2020; Yadav & Majumdar, 2024). In response, the circular economy (CE) paradigm has emerged as a regenerative alternative, reshaping value creation and resource use to retain the utility of materials through strategies such as refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Dey et al., 2022; Gennari, 2023; Sartal et al., 2020).

CE is now at the forefront of policy initiatives worldwide. The European Commission's Circular Economy Action Plans (2015, 2020) place CE centrally within the European Green Deal, signaling a strategic shift toward dual "green" and "digital" transitions (Findik et al., 2023; World Business Council for Sustainable Development & Metabolic, 2023). Instruments such as the forthcoming Digital Product Passport (DPP) under the EU's Ecodesign for Sustainable Products Regulation (ESPR) illustrate this nexus: mandating machine-readable, lifecycle-spanning records to ensure transparency, traceability, and regulatory compliance across sectors from batteries to textiles (Kühn et al., 2025; Van Engelenburg et al., 2022).

Yet behind these policy ambitions lie the realities of small and medium-sized enterprises (SMEs). SMEs are defined according to the European Commission as enterprises with fewer than 250 employees, and either an annual turnover not exceeding 50 million euros or an annual balance sheet total not exceeding 43 million euros (European Commission, n.d.). This definition is widely adopted across the EU research and policy framework, and it forms the basis for SME-related analysis throughout this thesis. SMEs constitute over 99% of EU businesses, contribute roughly half of total employment, and generate a substantial share of GDP (Binek & Al-Muhannadi, 2020; Dey et al., 2022; Gennari, 2023; Maher et al., 2023). Despite their critical economic and innovation roles, SMEs frequently struggle with operationalising CE strategies. Their constrained resource bases-limited capital, thin digital-skills pipelines, and modest managerial bandwidth-combine with fragmented supply-chain networks and sector-specific regulatory demands to create a highly challenging environment for adopting new digital and circular practices(Battistoni et al., 2023; Trevisan et al., 2023).

Research highlights that SMEs' CE engagements are often reactive, driven by external regulatory or market pressures rather than proactive strategic shifts(Binek & Al-Muhannadi, 2020; Gennari, 2023). Core business operations and near-term profitability frequently precede long-term sustainability investments (Dey et al., 2022). Moreover, SMEs face a pervasive lack of awareness about CE opportunities(Binek & Al-Muhannadi, 2020), insufficient internal expertise to manage complex digital tools(Battistoni et al., 2023), and uncertainty about return on information investments(Van Engelenburg et al., 2022).

Efficient, secure, and transparent information sharing across organizational boundaries is foundational for CE practices, enabling lifecycle monitoring, traceability, and data-driven decision-making(Khan & Abonyi, 2022; Kumar et al., 2016; World Business Council for Sustainable Development & Metabolic, 2023). Yet SMEs often encounter barriers such as poor IT integration, lack of common data standards, reluctance to disclose proprietary information, and perceived data-security risks(Bressanelli et al., 2019; Friedrich et al., 2025; Khan & Abonyi, 2022; Mahmud et al., 2021). Without addressing these obstacles, even the most sophisticated CE platforms-blockchain consortia, cloud-based DPP services, and IoT sensor networks-will fail to deliver on their promise of circularity.

In ubiquitous-computing and human-computer-interaction fields, "context-awareness" refers to a system's capacity to sense, interpret, and adapt to the dynamic conditions of its environment (Hong et al., 2009; Schilit & Theimer, 1994; Van Engelenburg et al., 2018). Context encompasses a spectrum of variables- technical infrastructure (Abowd et al., 1997; Eikerling, 2010; Van Engelenburg et al., 2018), organizational culture ("Changing with the Times: An Integrated View of Identity, Legitimacy, and New Venture Life Cycles", n.d.; Eller et al., 2020; Nguyen et al., 2015; Soni et al., 2023), regulatory regimes (Soni et al., 2023), trust relationships (Soni et al., 2023)- that collectively shape how information systems must operate to meet user needs. Yet CE literature has seldom leveraged this framing, treating digital tools as monolithic solutions rather than configurable systems attuned to user contexts.

It is shown that without explicit context-sensitivity, platforms risk misalignment (Janssen & van der Voort, 2016; Ølnes et al., 2017; Van Engelenburg et al., 2020): blockchain traceability may flounder when SMEs lack digital-readiness (Van Engelenburg et al., 2022); IoT monitoring may be underutilized if governance constraints preclude data sharing (Constantinides, 2012; Van Engelenburg et al., 2022; Van Engelenburg et al., 2020; Zeiss et al., 2020). This misalignment underscores the critical research gap: CE scholars have cataloged generic barriers but rarely translated context-awareness theory into practical guidance for tool selection and configuration tailored to SME realities (Van Engelenburg et al., 2022; Van Engelenburg et al., 2020).

In this thesis, an information-sharing system is understood as a configuration of digital tools - such as blockchain, DPPs, IoT, or cloud solutions - that enable the collection, processing, and exchange of data and information across multiple actors to enhance transparency, traceability, and collaborative decision-making (Bressanelli et al., 2019; Khan & Abonyi, 2022). SMEs selection of the right type of system depends on the surrounding factors in which they operate. The contextual factors are defined in this study as the operational, organizational, regulatory, and technological conditions that influence how SMEs adopt, configure, or benefit from information-sharing systems.

The CE digital technology landscape is notably diverse (Van Engelenburg et al., 2020): blockchain-based ledgers promise immutable provenance, digital-product-passport schemas encapsulate lifecycle records, cloud platforms offer scalable multi-tenant analytics, data-integration hubs mediate heterogeneous systems, semantic knowledge engines facilitate material reuse, and IoT systems deliver real-time monitoring (Van Engelenburg et al., 2022). While this innovation holds great potential, the sheer volume of options and the intricate trade-offs they entail (such as cost vs. capability, openness vs. control, integration effort vs. modularity). Without structured, context-aware selection processes, SMEs risk investing in ill-fitting platforms, undermining both technology adoption and CE outcomes. This is important since there are various solutions, and it is hard to say a solution is the best since the best solution for an SME would be dependent on the context the SME has, hence why it is important to look into the context SMEs have to choose the ideal information sharing tool.

1.1. Research Objective

This thesis addresses that gap through the design, development, and validation of a context-aware conceptual framework which operationalizes context sensitivity for CE information-sharing. The conceptual framework in this thesis will aim to link the contextual factors of SMEs to archetype combinations of information-sharing solutions. Such a framework could help SMEs identify and select digital tools, enabling them to be part of the CE while adapting to their contextual needs.

The main research question that allows us to answer this research gap is - *Which conceptual framework shows the relationship between context-based factors and information-sharing systems for circular business activities by SMEs?*

To answer the above research question, there are four sub-research questions:

1. *What characterizes the landscape of information-sharing systems available for circular business contexts?*
2. *What contextual factors should be addressed by a conceptual framework for SME information sharing in the circular economy?*
3. *How can these contextual factors be systematically mapped to appropriate information-sharing combinations within a framework?*
4. *To what extent does the developed conceptual framework support SMEs in making informed, context-aware decisions for information-sharing systems in the circular economy?*

The context-aware framework could offer SMEs a structured way to navigate the multitude of digital options by breaking down their technology choices into discrete contextual factors, potentially reducing the complexity and uncertainty that often accompany platform selection. Aligning recommendations with an SME's own operational and financial capacities may help firms prioritize investments that deliver the greatest informational return and encourage longer-term engagement with circular practices. Embedding regulatory pressure as the forthcoming Digital Product Passport requirements into the self-assessment process could enable SMEs to anticipate compliance needs and turn what might otherwise be seen as burdensome mandates into opportunities for strategic advantage. Guidance on governance configurations and data-sovereignty controls may foster greater trust and interoperability, which could support the multi-actor collaboration that is essential for effective circular ecosystems. Finally, by establishing a shared vocabulary around contextual factors and technology archetypes, the framework could improve communication among SMEs, technology providers, and policymakers, potentially smoothing implementation cycles and enhancing overall stakeholder alignment.

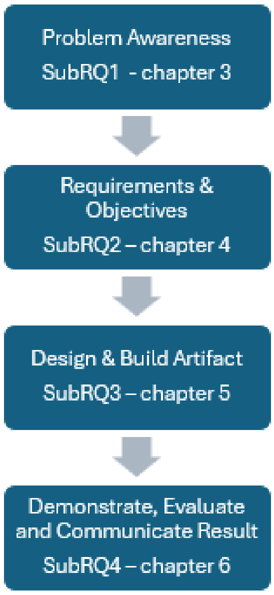
2 Methodology

This chapter outlines the methodological framework adopted for addressing the study's central research problem—supporting SMEs in selecting appropriate digital technologies for circular economy transitions through a context-aware decision-support framework. This study employs a Design Science Research (DSR) approach, which is particularly well-suited for generating actionable knowledge through the development of artifacts such as frameworks, models, and tools (Johannesson & Perjons, 2014). DSR is commonly applied in information systems research where complex socio-technical problems require context-sensitive solutions (Hevner et al., 2013; Peffers et al., 2007). The iterative nature of DSR aligns with the exploratory nature of this study, enabling continuous refinement through thematic coding, literature synthesis, and expert validation. Its focus on real-world relevance, problem-solving, and utility makes it ideal for developing a reproducible and practically useful framework to guide technology selection in SMEs engaged in circular economy initiatives.

The Design Science Research (DSR) methodology is selected because the research objective involves developing a conceptual framework tailored to SMEs operating under varying degrees of digital maturity and CE readiness. DSR allows for an iterative, problem-driven approach that connects theoretical understanding to actionable design. Unlike purely empirical methods, DSR is well-suited for situations requiring construct development, particularly when empirical generalization is not the primary aim. Given the novelty and complexity of CE policy instruments like the DPP, this research requires a methodology that could structure the problem space, build a targeted solution, and demonstrate its utility through real-world scenarios.

The research adopts a four-phase structure aligned with the sub-research questions (RQs). Sub-RQ1 involves identifying existing digital tools and their technological configurations relevant to circular economy transitions in SMEs. Sub-RQ2 focuses on uncovering contextual factors that condition the adoption of such tools. Sub-RQ3 integrates these insights to construct a conceptual framework linking the contextual factors with technology archetypes. Finally, Sub-RQ4 will aid in validating the framework created in the previous sub-research question. Each phase requires distinct yet interconnected methodological procedures, grounded in a structured and reproducible literature-based coding process. This chapter traces those procedures in detail, addressing both theoretical and empirical considerations, and clearly articulates how the methods ensure analytical transparency, rigor, and academic relevance.

Figure 2.1: DSR Flow



To understand the various tools available to achieve circular economy, this research applied a structured literature review, following PRISMA guidelines (Page et al., 2021). This process resulted in 31 academic papers that informed technology clustering in Chapter 3. In addition, grey literature such as EU-funded CORDIS reports is used to supplement context mapping in Chapter 5, though these sources are excluded from the formal SLR set.

To develop this framework, the literature associated with real-world tool deployments is analyzed to extract the underlying technologies (e.g., Blockchain, IoT, Cloud, Digital Product Passports). These are clustered into seven distinct technology archetype combinations. This literature-driven classification ensured that each archetype combination is grounded in sector-specific and pan-European project documentation, providing both ecological and academic validity.

The backbone of the analytical process involved a systematic qualitative coding of the selected literature, which allowed for the derivation of contextual factors influencing digital technology adoption by SMEs in the circular economy. A hybrid coding methodology is used, combining open coding and thematic analysis to identify recurring patterns and derive meaningful clusters from the literature. Open coding involves line-by-line tagging of qualitative data to extract contextually relevant concepts, such as “lack of digital skills,” “leadership openness,” or “policy pressure.” These codes are grounded in the empirical data drawn from the reviewed papers and technical project reports, ensuring that every coded insight is traceable to a credible source. In line with best practices for qualitative rigor (Nowell et al., 2017), the coding scheme is documented in a codebook that details each theme, its underlying codes, and definitions. Following the thematic identification of contextual factors, a key objective is to construct a robust, literature-based framework that maps these factors against specific technology combinations commonly deployed in SME circular economy initiatives.

Additionally, the technology-to-contextual-factor relationships are analyzed across sectors such as agri-food, textile, water, construction, chemical, and manufacturing. This sectoral lens strengthened the granularity of the mapping and enhanced its generalizability by demonstrating how certain technologies consistently aligned with contextual enablers or barriers across different industrial environments.

The framework that emerged from this mapping exercise formed a core analytical tool for this thesis, helping to bridge theoretical insights with practical decision-making tools for SMEs. It not only responds to SRQ3 but also serves as the foundation for the validation activities undertaken in SRQ4, where SME stakeholders are engaged to assess the plausibility and utility of the framework in real operational contexts.

To facilitate the mapping and validation of contextual factors to technology combinations, this research adopted a Low-Medium-High (LMH) ordinal rating system. This approach is widely used in qualitative research and multi-criteria decision-making (MCDM) to capture nuanced judgments without forcing numerical precision (Creswell & Poth, 2018). In the context of SME-level technology adoption, such subjective yet structured categorization provides a balance between empirical generalizability and contextual sensitivity (Venkatesh et al., 2012).

To evaluate the influence of contextual SME factors on the suitability of each technology archetype, this study applied a Low–Medium–High (LMH) ordinal rating scheme. This method is selected for its transparency, interpretability, and alignment with heuristic-based decision frameworks in design science (Hevner et al., 2013). The LMH approach enables the translation of nuanced qualitative insights into structured, reproducible judgments—particularly suitable for context-aware technology assessment (Nowell et al., 2017). Ratings are assigned based on triangulation across at least two sectoral or technical sources, ensuring empirical grounding. For example, for the contextual factor, it is rated high for the technology combination of DPP+BCP (Berger et al., 2023; Kühn et al., 2025; Orko & Lavikka, 2023). Similarly, the rest of the contextual factors are also rated, and the full matrix of LMH ratings and supporting sources is included in the appendix.

Finally, since these ratings are applied consistently across both the literature analysis and the validation interviews, they provide a transparent and reproducible mechanism for comparison. This alignment between deductive and inductive methods satisfies methodological triangulation principles (Patton, 2002), enhancing both the credibility and replicability of the findings.

To answer the last sub-research question, a qualitative validation strategy is adopted. Recognizing the time constraints and ethical considerations associated with data collection, a lightweight, semi-structured interview approach is selected over large-scale surveys. This approach aligns with qualitative research best practices in digital transformation and design science, ensuring depth and context-sensitivity (Seidel et al., 2009).

Three SME organizations are purposively selected for validation based on their direct engagement with circular economy initiatives and digital transformation trajectories:

- A circular solar panel manufacturing company enables reusability and disassembly in the sustainable manufacturing domain.
- A technology provider offering transparency and traceability solutions across industrial supply chains.
- A startup creating eco-friendly flame retardants derived from industrial sludge, operating across the chemical and materials sectors.

These firms are chosen due to their varied sectoral exposure, direct involvement in circular economy practices, and potential reliance on the technology archetypes identified in this research. The selection ensured theoretical saturation across sectors such as construction, manufacturing, and materials innovation.

This participatory validation loop served two purposes: (1) assessing the empirical fit of the literature-derived framework, and (2) refining it by surfacing real-world complexities, trade-offs, or overlooked nuances. While the sample size is intentionally small, the logic of analytic generalization (Yin, 2014) justified its use, especially within a design science research paradigm aimed at producing rigorously grounded yet usable artifacts.

In addition to the practitioner interview, the framework underwent a theoretical validation phase based on walkthrough-style applications using selected CORDIS and CIRPASS project documentation. This approach is grounded in the Design Science Research (DSR) paradigm, which recognizes that artifact evaluation can be both empirical and theoretical. Theoretical validation, particularly through case walkthroughs or illustrative applications, is an accepted method for demonstrating artifact relevance, logical soundness, and alignment with real-world problem contexts (Johannesson & Perjons, 2014). This method complements empirical validation by offering an additional layer of conceptual rigor, ensuring the framework's applicability beyond the immediate interview sample. The selected project is deliberately chosen for its alignment with the application phase of the framework, allowing for a coherent demonstration of its practical logic and utility.

The results of the interviews and walkthroughs are used to triangulate, corroborate, and — where necessary — adapt the contextual-technology mappings. This methodological transparency and academic grounding ensured that the validation process contributed not only to confirming but also refining the theoretical contributions of this thesis.

DSR Phase	Thesis Chapter	Explanation
1. Problem Explication	Chapter 3 – Problem Identification	Identifies CE-related barriers and challenges faced by SMEs.
2. Contextual factors derivation	Chapter 4 – Mapping Contextual Factors	Extract contextual SME needs using coded literature.
3. Artifact Design	Chapter 5 – Framework Design	Presents the conceptual framework linking the SME contexts to tool categories.
4. Demonstration	Chapter 5 – Framework Demonstration	Apply framework to simulated SME profiles (walkthroughs).
5. Evaluation and Communication(planned)	Chapter 6 – Evaluation	Describes semi-structured interviews and future validation with SMEs.

Table 2.1: Mapping of DSR Phases to Thesis Chapters and Explanations

3 Problem Identification

This chapter corresponds to the first phase of the Design Science Research (DSR). It is related to the Problem Identification phase. This chapter addresses the sub-research question ”What characterizes the landscape of information-sharing solutions available for circular business contexts?”. A structured literature review following PRISMA guidelines is used to answer this question. An open coding approach complements this. The literature review identifies and filters peer-reviewed academic sources, while open coding extracts discrete digital tool features. This was then subjected to thematic clustering to derive higher-order technological archetypes. The intended deliverable of this chapter is a foundational typology of seven distinct tool stacks, each linked to practical applications and considerations for return on information for SMEs.

First, the chapter details the PRISMA-based search strategy, which includes database selection, search terms, and inclusion and exclusion criteria. It then describes the open coding used to identify characteristics of digital tools systematically. It is then followed by thematic clustering, showing how the individual codes are clustered into technological archetypes. A concise discussion of scope-delimiting criteria for selecting the representative tool stacks concludes the methodological exposition. The chapter concludes by summarising the resulting typology and linking the insights into the derivation of the requirements phase of the DSR that is explored in Chapter 4.

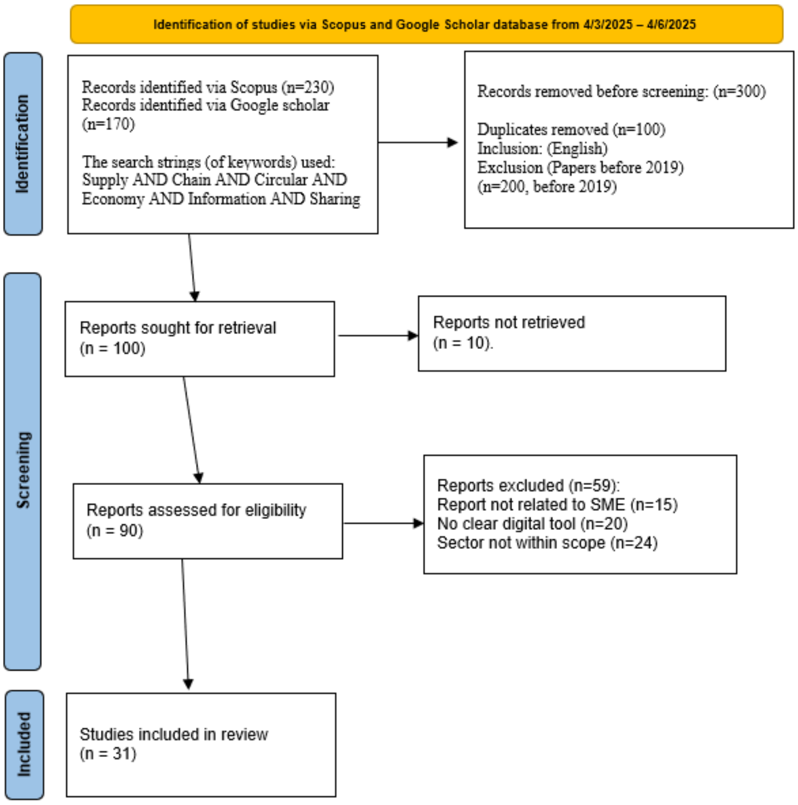
3.1. Data Collection

To characterize the landscape of information-sharing solutions, a structured literature review was conducted using PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Page et al., 2021). It was adapted to support an exploratory literature review. It helps to search, select, assess, and report relevant papers and literature for the review-based studies (Page et al., 2021). Figure 3.1 presents the PRISMA flow diagram, which summarizes the screening and selection process.

The literature search was done on sites such as Google Scholar and Scopus. The search strategy employed in Scopus was TITLE-ABS-KEY(“circular economy” AND ”supply chain” AND ”Information Sharing”). This was used verbatim and with some variations. The variations included trying to see how the outputs would be when trying to search for particular sectors using terms like ”Agrifood SME”, ”Chemical SME”, etc. Further, phrases such as ”data sharing in the agrifood supply chain” OR ”Barriers to the digital platform in chemical supply chains” OR ”Information sharing for manufacturing SME” were used in Google Scholar’s advanced search with all of the words applied. The search was carried out between the 4th of March and the 4th of June. The main focus was to ensure the papers retrieved were in English. The search on SCOPUS yielded in total of 230 papers, and on Google Scholar yielded 170 results. Further, the papers that were published before 2019 were removed, and duplicates were removed as well. Papers published before 2019 are excluded to emphasize recent studies, as the literature on information-sharing and circular economy has notably grown in the past few years. The initial search yielded over 400 articles and reports from both Google Scholar and Scopus. After gathering the initial results, the articles and reports retrieved were screened, out of which, based on the inclusion and exclusion criteria as explained above, only 100 were sought for retrieval. Further, out of the 100, 10 were not retrievable due to a lack of access.

From the 90 papers retrieved, further narrowing down to the final literature was done. Literature that was not pertinent to SME, no mention of any clear digital tool, and those not in the selected scope of sectors were removed. This narrowed down the literature from 90 to 31, where in total 59 articles were removed, out of which 15 were not pertinent to SME, 20 articles had no mention of any clear digital tool, and finally, 24 were not related to the sectors chosen for this research. The selected documents cover six critical sectors: agrifood, chemicals, construction, manufacturing, textiles, and water.

Figure 3.1: PRISMA



This data collection process served as the foundation for the subsequent coding analysis, enabling the identification of recurring technologies and their contextual applications across domains. The selected studies were subjected to qualitative coding in an inductive manner for the literature analysis, and the coding was done in Excel. Open coding was used to extract key descriptors of the digital tools, including functionality (e.g., traceability, reporting), and technology type (e.g., blockchain, cloud, DPP). This allowed the development of a broad landscape of digital technologies, forming the basis for identifying recurring tool features across cases.

The following table shows the overview of the 31 papers across the six sectors.

Table 3.1: Literature Overview

Author	Year	Sector	Digital Tool
Namagembe & Mbago	2023	Agrifood sector	Information sharing systems; managerial control systems
Biasino Farace & Angela Tarabella	2024	Agrifood sector	IoT sensors; hydroponic digital control; integrated production IS
Durrant et al.	2021	Agrifood sector	Data Trusts; Semantic Web; Blockchain; AI; privacy-preserving technologies
Sonar et al.	2023	Agrifood sector	Wings method (decision modeling); tech adoption framework
García-Álvarez de Perea et al.	2019	Agrifood sector	Traceability tools; innovation-driven ICT; inter-firm digital collaboration
Orko & Lavikka	2023	Chemical sector	Data platforms; digital passports; material databases; hybrid platform ecosystems
Berger et al.	2023	Chemical sector	Digital Product Passports (DPP); stakeholder mapping tools; TOE & DOI frameworks
Ma, Shi & Kang	2023	Chemical sector	Digital transformation; blockchain; traceability systems; information-sharing platforms
Ozbiltekin-Pala & Aracıoglu	2024	Chemical sector	Digital transformation; data management; digital storage
Kühn et al.	2025	Chemical sector	Digital Product Passport using Asset Administration Shell (AAS) framework
Kovacic, Honic & Sreckovic	2020	Construction sector	BIM; BIM-based Material Passports; laser scanning; GPR; gamification platforms
Wuni & Shen	2022	Construction sector	BIM; document management systems; Just-in-Time delivery; circular design tools
Yu et al.	2022	Construction sector	BIM; GIS; RFID; blockchain; big-data analytics; IoT; modelling & simulation
Thirumal et al.	2024	Construction sector	AI; BIM; IoT; blockchain; digital twins; RFID; digital marketplaces; GIS; implementation barriers
Wang et al.	2020	Construction sector	Blockchain-based smart contracts; BIM integration; real-time traceability; digital ledgers
Rosa & Terzi	2023	Manufacturing sector	AI-based circularity tools; eco-design platform; CE dashboard; TREASURE information-sharing system
Battistoni et al.	2023	Manufacturing sector	Sensor, integration, intelligence, and response layers; Industry 4.0 tools (IoT, AI, ERP)
Winter et al.	2023	Manufacturing sector	Digital information-sharing platforms; MSCM analytics; SPSS surveys; supply-chain dashboards
Pedone et al.	2021	Manufacturing sector	DigiPrime platform; OSaaS; CE data-federation tools
Jäger-Roschko & Petersen	2022	Manufacturing sector	Centralized CE databases; RFID product tags; blockchain; digital twins; lifecycle data platforms
Hader et al.	2022	Textile sector	Blockchain; big data; smart contracts; RFID; MongoDB; BigchainDB-TSC platform
Heim & Hodson	2023	Textile sector	Web3 platforms; smart tags; forensic tracers; Open Apparel Registry; DPP; Rest API
Rinaldi et al.	2022	Textile sector	UNECE traceability tools; smart labels; transparency frameworks; UN/CEFACT Rec. 46
Chen	2024	Textile sector	Blockchain for traceability; smart contracts; circular-supply-chain platforms; Five-R framework
Kazancoglu et al.	2022	Textile sector	DEMATEL-Fuzzy barrier assessment; systemic digital-transformation framework
Arranz et al.	2024	Water sector	Organizational barriers to CE implementation; Smart water platform; remote sensing
Kathambi et al.	2021	Water sector	OECD Water Governance Framework
Liu, Yang & Yang	2021	Water sector	IoT; fuzzy-Delphi; digital CE systems
Cahn et al.	2023	Water sector	Data-as-a-Service; PPP-based cloud analytics
Hernández-Chover et al.	2022	Water sector	Digital twins; AI; cloud computing; real-time sensors
Mbavarira & Grimm	2021	Water sector	CE systems mapping; DPPs; SCADA

3.2. Structured Literature Review and Open-Coding

A literature review is conducted to identify the types of digital tools found in practice. Grey literature and EU project summaries were intentionally excluded to maintain the scholarly rigor required for the inductive thematic analysis. Next, an open coding process is initiated so that it identifies relevant digital tools for information sharing in circular business contexts. After reviewing peer-reviewed articles from the six target sectors, each paper is examined for descriptions of the function or purpose of digital solutions. While EU projects and grey literature are excluded from the SLR, they are examined during the coding phase to complement academic findings and generate additional open codes. These observations are distilled into concise descriptors or 'codes' that capture the functionality or contribution of each tool. These codes are iteratively recorded and organized into a codebook using a spreadsheet, forming the foundation for thematic analysis. Continuous refinement and addition to the codebook are done when novel features or applications are encountered until no new codes appear. This coding process leads to the systematic identification of commonalities across tools, such as those supporting traceability, environmental data sharing, or compliance facilitation.

Sector-specific findings begin below.

Agrifood Sector

In the agri-food sector, digital tools tend to emphasize traceability, sustainability monitoring, and support for decision-making in complex supply chains, especially for micro, small, and medium enterprises (MSMEs). Solutions range from IoT and blockchain technologies that can offer end-to-end product visibility to analytics platforms facilitating real-time feedback and transparency. (Durrant et al., 2021; Namagembe & Mbago, 2023) examines the dynamics of supply chain collaboration and resilience in agri-food contexts, particularly how external shocks such as the COVID-19 pandemic influence coordination among actors. Their analysis aligns with the descriptors from the codebook, such as ”platform architecture”, ”stakeholder coordination”, and ”data-driven resilience” .

Further, (Farace & Tarabella, 2024) investigates how Industry 4.0 capabilities and supply chain integration may affect the sustainability performance of agricultural supply chains, noting that enhanced digital integration appears to improve traceability and circularity efforts. (Sonar et al., 2024) identifies barriers such as a lack of information and poor post-harvest handling among Indian MSMEs, which could hinder digitalization among Indian MSMEs. Their discussion maps onto codes such as ”sustainability barrier mapping”, ”strategic decision aid”, and ”post-harvest traceability”.

(García-Álvarez De Perea et al., 2019) compares SME and MNE internationalization models, showing they share a common archetype characterized by risk-minimized innovation and a focus on meeting consumer demands. These insights align fit within the codebook categories of ”collaborative innovation”, “market-responsive design”, and “consumer-driven tool configuration”. Overall, the agri-food literature suggests a layered landscape where traceability is foundational, yet broader adoption may be constrained by infrastructural and strategic limitations, especially among MSMEs. The open coding process links technical capabilities with functional demands, whether environmental reporting, consumer assurance, or regulatory alignment. This indicates a need for interoperable, adaptable, and context-specific digital ecosystems.

Chemical Sector

In the chemical sector, digital tools such as Digital Product Passports (DPPs), IoT platforms, and multi-stakeholder data-sharing frameworks are increasingly applied to address gaps in material traceability and lifecycle transparency. (Berger et al., 2023) shows how stakeholders in electric vehicle battery systems perceive DPPs as instrumental for sustainable product management, an insight that corresponds to codes such as “battery value-chain digital platform”, “sustainability performance enablement”, and “DPP adoption framework”. Using the Diffusion of Innovation (DOI) theory and the Technology-Organization-Environment (TOE) framework, the paper captures enablers and barriers for DPP diffusion among various adopter categories, adding nuance to how tools are adopted in industrial settings.

The importance of interoperability emerges in (Ozbiltekin-Pala & Aracıoglu, 2024), which argues that data platforms need to handle dynamic, real-time exchanges, observation captured by ”inter-organizational integration” and ”real-time coordination infrastructure”. (Orko & Lavikka, 2023) highlights digital maturity challenges for SMEs, especially when standardized data models and secure protocols are absent, which aligns with “digital readiness assessment”, “interoperable standardization”, and “secure communication framework”.

Predictive analytics and AI for waste-stream optimization are discussed by (Ma et al., 2022), introducing codes such as “waste stream digitalization”, “predictive circular intelligence”, and “machine learning for resource recovery”. (Kühn et al., 2025) synthesizes multiple industry pilots and advocates digital platforms that could enable traceability from raw material input to end-of-life stages (“lifecycle transparency tools”, “compliance-oriented data hubs”, and “modular data passports”). Collectively, these studies indicate a convergence between policy-mandated transparency and innovation-driven optimization, with digital tools positioned to deliver real-time data integration, predictive insights, and multi-actor interoperability.

Construction Sector

In the construction sector, digital tools are increasingly sought to address inefficiencies in waste management, material reuse, and coordination across fragmented value chains. Building information modeling (BIM) integrated with digital twins appears to enhance traceability, design-for-disassembly, and lifecycle assessment. These insights correspond to codes like “BIM-Digital Twin integration”, “disassembly lifecycle mapping”, and “traceability-enhanced modeling” by (Yu et al., 2022).

Blockchain applications in the construction supply chain are explored by (Wuni & Shen, 2022), who suggests they may help mitigate fraud and foster trust, especially in demolition and salvage contexts (“fraud prevention via blockchain”, “trust enhancement protocols”, and “material salvage traceability”). (Iva Kovacic et al., 2024) examines digital construction passports as central repositories for product origin, composition, and environmental data (“construction digital passport”, “environmental performance ledger”, and “compositional transparency hub”).

SME-specific challenges are emphasized by (Thirumal et al., 2024), including digital illiteracy and limited adoption of circular tools due to unclear value proposition and training deficits. Their analysis aligns with new codes such as “SME adoption constraints”, “digital literacy enabler”, and “value proposition articulation”. Together, these insights illustrate that construction-sector digital tools are evolving toward multi-functional platforms that support both operational efficiency and regulatory alignment. Open coding analysis supports this by surfacing needs for modularity, user-centric design, and real-time feedback mechanisms to ensure stakeholder engagement across the project lifecycle.

Textile Sector

In the textile sector, digital tools are being developed to enhance transparency, traceability, and circularity throughout the supply chain. (Hader et al., 2022) demonstrates garment supply-chain mechanisms that can provide visibility from raw fiber to retail (“garment supply chain traceability” and “fiber authentication system”).

Eco-labelling initiatives driven by EU policy underscore the demand for standardized, interoperable digital labels (Heim & Hodson, 2023) (“digital labeling mechanism” and “eco-label standardization”). (Rinaldi et al., 2022) shows how circular-design principles may be embedded via visualisation, and digital twin(“circular design integration” and “lifecycle impact visualization”).

AI-based sorting for post-consumer waste is illustrated by (Chen, 2024) ("post-consumer textile recovery"), while blockchain-enabled traceability is examined by (Kazancoglu et al., 2022) ("blockchain for transparency," "stakeholder trust framework"). Collectively, the textile literature suggests that cohesive digital systems could align material tracking with circular business models and evolving regulatory requirements.

Manufacturing Sector

Within manufacturing, information-sharing tools aim to coordinate supply-demand data and improve visibility in dynamic production networks. (Winter et al., 2023) reports a multi-tier integration tool that may reduce data disparities("multi-tier information integration", "MSCM data disparity reduction", "supplier network transparency").

Digital platforms offering "operation-services-as-a-service" (OSaaS) are analyzed by (Pedone et al., 2021). These solutions enable SMEs to access planning, inventory, and energy analytics, without reliance on heavy IT investments("cross-sectoral data service platform", "operational services as a service", "reverse logistics coordination").

Decentralised control via agent-based systems and edge computing is explored by (Battistoni et al., 2023)("decentralized information control", "agent-based data coordination"). (Rosa & Terzi, 2023) provides a case that shows how digital manufacturing systems can promote closed-loop operations("integrated product lifecycle platform", "closed-loop information architecture"). Overall, these tools appear to facilitate coordination, modular services, and system-wide visibility, suggesting the value of SME-friendly solutions in dynamic manufacturing settings.

Water Sector

In the water sector, digital tools increasingly serve water resource management, environmental monitoring, and transparency in utility operations. (Arranz et al., 2024) examines smart water platforms that leverage remote sensing and analytics ("predictive environmental monitoring", "real-time data visibility"). Blockchain-based quality assurance is investigated by (Liu et al., 2021) ("blockchain-enabled trust," "quality-verification traceability," "secure environmental reporting"). These tools help monitor contaminants and improve the reliability of data transmission between upstream water suppliers and downstream users.

(Cahn et al., 2023) describes integrated platforms for wastewater treatment optimization and infrastructure maintenance ("infrastructure maintenance planning", "wastewater process integration", and "IoT-based leakage detection"). Deploying sensors and AI models for predictive analysis enhances decision-making capacity and resource efficiency. (Mbavarira & Grimm, 2021) addresses policy compliance and community data sharing in water-scarce regions. Their work relates to "policy compliance facilitation", "mobile water reporting tools", and "community-centric information systems".

A regional dashboard that consolidates multi-source environmental data is presented by (Bessy Eva Kathambi et al., 2021) ("regional dashboard integration" and "multi-source data harmonization"). Collectively, the sector's studies indicate a trend toward smart, interoperable systems that support resilience, accountability, and inclusive governance in resource management.

The Open coding was done, and we identified around 200 codes across all the literature. Here is an example of the codes gathered, and the rest is attached to Appendix A.2.

Table 3.2 shows a sample of our open codes; the complete codebook is in Appendix A.

No.	Code	Key Citation
1	19 critical barriers via Pareto analysis	(Thirumal et al., 2024)
2	22 barriers—infra/econ, tech, governance groups	(Liu et al., 2021)
3	37 barriers → 9 thematic categories	(Thirumal et al., 2024)
4	3-level ROI model for transformable buildings	("Circular Construction In Regenerative Cities (CIRCuIT)", 2025)
5	48 SME-led grants & matchmaking programs	(DigiCirc Consortium, 2024)

Table 3.2: Excerpt of Open Codes (full list in Appendix A.1)

Together, the insights from the six sectors reflect a rich and complex digital tool landscape shaped by sector-specific needs and technological capabilities. The open coding process has produced a diverse set of functional descriptors that capture how digital tools contribute to information sharing in circular contexts. However, these codes—while illuminating in isolation—require further synthesis to identify broader thematic structures. In the next section, these codes are clustered into higher-order archetypes to uncover the core technological patterns that can guide the development of context-aware frameworks for SMEs.

3.3. Clustering Process

Together, the insights from the literature reflect a rich and complex digital tool landscape shaped by sector-specific needs and technological capabilities. Grey literature, along with EU projects, provides pilots that focus on SMEs and help ground the archetype code in actual implementations and cross-check the academic proof. The PRISMA protocol is applied exclusively to peer-reviewed academic articles. Grey literature and EU-funded projects, which are excluded from the SLR, are coded separately after the SLR and added to the clustering process to provide practical insights and support the academic findings.

To advance from a fragmented list of digital tools to a coherent understanding of their technological underpinnings, a clustering process is conducted. This involves systematically examining the functional codes and grouping them into six distinct technological archetypes based on shared digital infrastructure, underlying architecture, and intended functional outcomes. The resulting archetypes—Blockchain-Based Ledgers (BCL), Digital Product Passports (DPP), Cloud Platforms (BCP), Data Integration Hubs (DIH), Semantic Knowledge Platforms (SEM), and IoT + Real-Time Monitoring Systems (IoT)—offer a consolidated view of the core digital enablers driving information exchange across CE-relevant sectors.

The clustering approach relies on the co-occurrence and thematic similarity of open codes. Codes related to decentralized transaction logging, immutability, and trust-building mechanisms are grouped under the BCL archetype. For instance, codes such as "blockchain for transparency", "fraud prevention via blockchain", and "blockchain-enabled trust" emerged consistently across sectors like construction (Wuni & Shen, 2022), textile (Kazancoglu et al., 2022), and water (Liu et al., 2021), illustrating their widespread relevance. BCL systems provide tamper-proof records of material provenance and compliance assurance, making them pivotal in ecosystems where data verifiability and auditability are crucial.

Digital Product Passports (DPPs) are clustered around codes such as "compliance-oriented data hubs", "modular data passports", "battery value-chain digital platform", and "digital construction passport". These solutions can support traceability and data accessibility across product lifecycles, offering contextual visibility for environmental and performance indicators. DPPs have been extensively referenced in the chemical (Berger et al., 2023), construction (Iva Kovacic et al., 2024), and textile sectors (Kazancoglu et al., 2022), and serve as scalable frameworks for exchanging structured product data aligned with policy compliance.

Cloud Platforms (BCP), especially those supporting multi-tenant architectures, encapsulate tools designed for real-time responsiveness and cross-organizational operability. Codes like “cross-sectoral data service platform”, “reverse logistics coordination”, and “inter-organizational integration” highlight how SMEs can use shared infrastructure without investing in bespoke IT systems. Such archetypes are evident where industrial symbiosis and dynamic coordination benefit from central data platforms (Ozbiltekin-Pala & Aracıoglu, 2024; Pedone et al., 2021). While the codes could appear applicable to BCL archetype, the usage in the literature emphasizes centralized coordination and real-time interoperability, which aligns more with BCP.

The DIH archetype brings together codes that focus on aggregating and structuring information across disparate systems. These include “interoperable standardization”, “data integration architecture”, and “real-time coordination infrastructure”. Particularly in the chemical and manufacturing sectors (Orko & Lavikka, 2023; Rosa & Terzi, 2023), these hubs act as middleware that translates heterogeneous datasets into harmonized streams, crucial for predictive analytics and performance benchmarking.

Semantic Knowledge Platforms (SEM) were defined through codes like “semantic matching for material reuse”, “AI-supported classification”, and “stakeholder trust framework”. These tools leverage machine learning and logic-based models to assign meaning to data, promoting intelligent automation and decision-making. Their relevance is prominent in sectors where material reuse, design adaptation, and intelligent retrieval are key, as seen (Kühn et al., 2025; Rinaldi et al., 2022).

Finally, the IoT + Real-Time Monitoring Systems (IoT) archetype encompasses codes tied to sensing, tracking, and environmental data capture. Examples include “post-consumer textile recovery”, “lifecycle impact visualization”, “IoT-based leakage detection”, and “predictive environmental monitoring”. These tools are critical in real-time compliance reporting and operational optimization across sectors like textile, agri-food, and water (Arranz et al., 2024; Chen, 2024; Sonar et al., 2024).

The clustering process was further enriched by referencing EU-funded project documentation. For instance, the classification of DIH through its focus on federated knowledge platforms, REST APIs - based on interoperability, and supply chain data standardization (DigiCirc Consortium, 2024). It is seen that both the DPP and SEM archetypes showcase modular material passports, EPCIS schema integration, and semantic classification techniques (“European Union 2024”, 2025). CIRPASS contributed extensively to the DPP cluster with its emphasis on compliance-oriented data models and lifecycle product traceability using cloud-based architecture (Bernier et al., 2024). The SCIRT project demonstrated real-time textile tracking with IoT sensor platforms and QR-based item tagging, reinforcing both the DPP and IoT clusters (European Union, 2024c). A decentralized traceability infrastructure powered by Hyperledger and smart contracts was shown to support BCL (European Union, 2022). Each of these projects reinforced specific code-level classifications and provided empirical support for distinct archetypes without crossing into combinatory configurations. These codes, such as ”semantic lifecycle labeling”, ”blockchain-based certification”, ”federated middleware”, and ”IoT edge feedback loop”, were added directly to the open codebook and mapped uniquely to individual archetypes. This structured approach further anchored the clustering in real-world applications, strengthening its analytical and empirical foundation.

This archetypal framework enhances the analytical clarity of digital tool categorization by emphasizing core infrastructural logic rather than sector-specific functionalities. By abstracting open codes into modular archetypes, this clustering enables a scalable and comparative view of digital solutions across industry contexts. The identified archetypes provide the foundational building blocks upon which the next stage—technology selection and integration into the framework—can be constructed, ensuring relevance to SME capabilities and circular economy objectives. Each archetype encapsulates a recurring set of infrastructural technologies—e.g., cloud-native dashboards, QR/RFID tagging, edge computing, and EPCIS schemas—used across sectors.

The identification of the six technology archetypes is derived from a structured analysis of derived literature, which is coded using a dedicated codebook (see Appendix A.2). This approach helps ensure a transparent and methodological selection process grounded in academic and EU project sources.

3.4. Combination

This section presents a set of seven archetype combinations that reflect how the archetypes identified in the previous section are used in tandem based on the literature used in this study. This section builds on by identifying combinations of archetypes found particularly in EU-funded circular economy projects and SME case studies. The goal here is not to suggest combinations but to highlight the ones that SMEs are likely to encounter. This serves as the base for the mapping created in Chapter 5 in combination with the contextual factors identified in the next chapter.

By showing how the archetypes are coupled as solutions, this section contributes to the first subquestion by highlighting not only the existence of these combinations but also how they could be integrated in circular business contexts.

Table 3.3: Technology–Archetype Combinations and Key Sources

Technologies	**Archetype combinations**	**Sources**
Hyperledger Fabric, EPCIS schema; Smart contracts	BCL + DPP	(Berger et al., 2023; European Union, 2022; Iva Kovacic et al., 2024; Kazancoglu et al., 2022)
Multi-tenant cloud systems with REST APIs; Lifecycle Analytics	BCP	(Bernier et al., 2024; Ozbiltekin-Pala & Aracıoglu, 2024; Pedone et al., 2021)
Hyperledger Fabric, Smart Contracts	BCL	(European Union, 2022; Liu et al., 2021; Wuni & Shen, 2022)
Federated middleware layer, REST APIs, Data-sovereignty tools	DIH	(Orko & Lavikka, 2023; Rosa & Terzi, 2023)
Modular material passports, EPCIS schema, QR/RFID tagging	DPP + BCP	(Berger et al., 2023; Kühn et al., 2025)
IoT sensor gateways, Edge computing nodes, Blockchain anchoring	IoT + BCL	(Chen, 2024; European Union, 2022; Sonar et al., 2024)
Digital twin models, IoT gateways with REST APIs	IoT + BCP	(Cahn et al., 2023; Mbavarira & Grimm, 2021)

The BCL + DPP combination, featuring technologies such as Hyperledger Fabric, EPCIS schema, and smart contracts, is supported across multiple sources. Academic literature supports discussing blockchain integration into product passports for traceability and compliance (Berger et al., 2023; Iva Kovacic et al., 2024), while the CircThread and Tilkal projects exemplify practical implementation of such stacks for textile and food supply chains (European Union, 2022). These tools exemplify the convergence of decentralized trust with structured product data governance.

The BCP archetype—represented once to prevent redundancy—includes platforms like multi-tenant cloud systems with REST APIs and lifecycle analytics. The cloud-hosted infrastructures enable SMEs to manage lifecycle data affordably and scalably (Bernier et al., 2024; Ozbiltekin-Pala & Aracıoglu, 2024; Pedone et al., 2021).

BCL as a standalone archetype was retained due to its strong sectoral presence. Use cases from in-water management and in-construction justify selecting blockchain for trust and immutability (Liu et al., 2021; Wuni & Shen, 2022). The Tilkal project further supports BCL through real-time data verification for compliance across the supply chain (European Union, 2022).

DIH is represented through federated middleware systems incorporating REST APIs and data governance tools. This was mentioned in the literature and further supported by CE-Rise and Digicirc EU projects, which emphasized distributed data exchange infrastructures in manufacturing and industrial symbiosis contexts (Orko & Lavikka, 2023; Rosa & Terzi, 2023).

The DPP + BCP combination—using material passports with EPCIS and QR/RFID—was reflected in the literature (Berger et al., 2023; Bernier et al., 2024; European Union, 2024c; Kühn et al., 2025)where these tools facilitated downstream product data exchange and recovery monitoring. IoT + BCL, combining sensor infrastructure with blockchain anchoring, emerged (Chen, 2024; European Union, 2022; Sonar et al., 2024). Lastly, IoT + BCP—realized through digital twins, REST APIs, and IoT gateways (Angarita-Zapata et al., 2021; Liu et al., 2021). These configurations enabled predictive analytics and condition-based decision-making in water and manufacturing systems, making them particularly suitable for dynamic circular environments.

Finally, the configuration involving IoT sensor gateways, edge computing infrastructure, and blockchain anchoring links the IoT and BCL archetypes. It appeared in applied case studies where real-time monitoring was essential for operational decision-making, and blockchain added data integrity guarantees (Chen, 2024; Sonar et al., 2024). This hybrid model was especially effective in the agri-food and textile sectors, where environmental metrics needed secure logging to satisfy regulatory and consumer demands.

An additional combination features digital twin models, IoT gateways, and REST APIs—classified under the IoT + BCP archetype. The digital twin model enhances context-aware visualization of asset conditions, while REST APIs enable integration across cloud-hosted systems. This combination proves particularly suitable for dynamic environments where continuous feedback and system flexibility are required, such as in circular manufacturing and water reuse ecosystems (European Union, 2024c, 2025c).

In narrowing the final list to these seven, attention was given not only to technological diversity but also to ensuring that all archetypes—BCL, DPP, BCP, DIH, SEM, and IoT—were reasonably represented, either singularly or in combination. Although the SEM archetype was identified during clustering, it was underrepresented across the reviewed literature. Therefore, it was not included as a standalone configuration in the final selection. Furthermore, while additional combinations could plausibly be derived, these seven represent the most empirically supported, cross-sectorally relevant, and functionally comprehensive patterns observed in the reviewed literature.

3.5. Conclusion

This chapter addresses sub-research question 1 - ”What characterizes the landscape of information-sharing solutions available for circular business contexts?”. To answer this, a structured literature review is conducted using the PRISMA approach. The academic literature is screened and analyzed through open coding and clustering. This helps in identifying the six main archetypes of digital tools used in circular settings, which are BCL, DPP, BCP, DIH, SEM, and IoT. These archetypes are then grouped into seven combinations to show plausible archetype combinations.

The findings offer a literature-informed view of the archetypes could occur in practice. The insights from this chapter serve as a starting point for the next phase of research, where we identify the various contextual factors SMEs have and need. This is done in Chapter 4, and further, this helps in the mapping process, which is done in Chapter 5 to create the conceptual Framework.

4 Contextual Factors

Traditionally, the next phase after problem explication in the DSR is the requirement derivation phase. In this thesis, a modest deviation is made by focusing on identifying the contextual factors relevant to SMEs for adopting information sharing systems and being part of circular economy settings. This is done since the conventional requirements could be less informative for developing a conceptual framework. Given the diverse, evolving, and resource-constrained environment that SMEs operate in, contextual factors could offer a more flexible and grounded basis for informing the selection and configuration of digital information-sharing systems.

This chapter looks into the second sub-research question of the thesis, which is ”What contextual factors should be addressed by a conceptual framework for SME information sharing in the circular economy?”. The focus is on identifying contextual factors that may help SMEs adopt digital information sharing systems, specifically within CE initiatives. These contextual factors are expected to contribute to the conceptual and empirical foundation for the conceptual framework that is developed in the next phase. In this study, a contextual factor refers to a condition or attribute within the operational, organizational, or regulatory environment of SMEs that influences the adoption and use of digital information-sharing technologies.

To ensure a transparent and systematic approach, this chapter applies a structured methodology that combines open coding, thematic clustering, and frequency-based prioritization. The coding process is applied to literature and documentation that addresses SME experience with digital technology in CE settings. The goal is to identify recurring themes that reflect challenges or enable relevant information sharing. While some of these contextual factors may also appear in broader digitalization efforts, the interpretation and selection in this chapter are grounded in their relevance to circular economy transitions. While challenges and enablers from the literature are part of the initial coding process, they are framed here as contextual factors because they represent conditions that must be considered for successful adoption of information-sharing technologies rather than isolated problems or advantages. The outcome of the coding and clustering process is a set of contextual factors that capture the operational and environmental conditions SMEs face, forming the foundation for the mapping done in Chapter 5. The chapter first outlines the coding procedure, then the clustering process, presents the selected factors, and concludes with a reflection on their overall framework design.

4.1. Literature review and Open coding

To identify contextual factors relevant for SMEs adopting digital tools in circular economy transitions, this study applies a qualitative coding process based on open coding principles. While the approach draws on open coding to remain inductive and grounded in literature, the coding focuses on surfacing factors that influence digital technology decisions. Not all insights extracted from the literature are treated as contextual factors; only those that relate to SME conditions, barriers, or enablers that may affect the adoption or configuration of information-sharing tools are retained. This selective application of open coding aligns with the objective of this DSR phase, which is to derive factors based on real-world contexts. The process of selecting the literature is explained in 3.1.

The literature reviewed in this sector spans six sectors: agrifood, textiles, chemicals, construction, manufacturing, and water. These sectors are selected based on their frequent appearance in the context of SME involvement and digital transformation challenges. They represent diverse but highly relevant domains where information-sharing plays a critical role in enabling circular practices. By identifying contextual barriers and enablers across these sectors, this study aims to surface cross-cutting patterns that can inform the design of a generalizable yet context-aware framework. The sectoral lens aids in ensuring the resulting factors are informed by practical CE implementations and reflect contextual specificity rather than relying solely on abstract generalizations. The sectors are not contextual factors themselves; rather, they provide the settings in which the contextual factors manifest with different levels of intensity or importance.

The coding procedure followed a structured but flexible approach to identify context-specific factors for digital information-sharing in the circular economy transition. Each selected literature is reviewed in detail, and relevant text segments are highlighted if they reflect conditions that might influence SME decision-making in digital adoption. A piece of text is included as code if it describes a factor that appeared to influence how SMEs approach, adopt, or respond to digital information-sharing technologies in CE contexts. The text segments are paraphrased into short descriptive expressions, forming the basis for initial open codes. The codes are only included if they are relevant to the configuration or uptake of information-sharing tools by SME in CE setting throughout the process. The set of identified codes is documented in Appendix B, together with their source reference, to support transparency and traceability. Having outlined the coding and selection procedure, the following presents the key contextual factors identified through this process, along with illustrative examples from the literature.

The digital transformation of the agrifood sector is shaped by complex supply chain structures, diverse market demands, and regulatory fragmentation. The literature repeatedly stresses that the absence of integrated information flows hampers both transparency and operational efficiency. It is noted that “A holistic framework for continuous data and information flows is lacking”, making it difficult for SMEs to achieve comprehensive digitalization (Iva Kovacic et al., 2024, p. 3). This gap is exacerbated by persistent “barriers related to recycling technologies, digital technology know-how, and the lack of CE awareness”, which are particularly acute for smaller actors in the value chain (Liu et al., 2021, p. 7). The need for collective action emerges from studies highlighting that “alliances reduce innovation barriers” and that “collaboration enables resource pooling” (García-Álvarez De Perea et al., 2019, p. 7). At the same time, challenges such as “difficulty aligning quality standards internationally” and “challenges in cross-border logistics” reflect the external pressures facing these SMEs (Farace & Tarabella, 2024) (Namagembe & Mbago, 2023, p. 6). Empirical research further reveals that “market entry barriers for SMEs” and “limited access to foreign market information” constrain expansion, while “trust in international alliances” and “competition fosters collaborative innovation” become pivotal for firms seeking to overcome fragmentation and exploit digital opportunities (García-Álvarez De Perea et al., 2019; Namagembe & Mbago, 2023).

The construction sector presents unique digitalization challenges rooted in project-based organization, stakeholder heterogeneity, and evolving regulatory demands. The literature characterizes the sector’s current state as one in which “Construction sector faces new obstacles due to increasing complexity and stakeholder diversity” (Thirumal et al., 2024, p. 2). This complexity often manifests in “supply chain fragmentation”, which inhibits data sharing and leads to persistent “compliance overload” (Omrani et al., 2024a) (Wuni & Shen, 2022). The uneven nature of digital maturity across stakeholders—reflected in “tiered trust levels” and “communication lags”, creates further obstacles to the adoption of shared platforms (Pedone et al., 2021; Wuni & Shen, 2022). Regulatory hurdles are also pronounced, as evidenced by the prevalence of “regulatory barriers to digital tech adoption” (Ozbiltekin-Pala & Aracıoglu, 2024). Studies also note that "certification-driven data demands" can drive or inhibit technology uptake depending on SME capacity, highlighting the sector's dual challenge of compliance and operational effectiveness (Tsvetkova et al., 2020).

Chemical SMEs must navigate a high-risk, compliance-driven environment in which data security and regulatory alignment are paramount. The theoretical literature underlines the strategic value of digital solutions in ensuring safety and transparency, but also the profound reluctance to share sensitive data. It is demonstrated that "blockchain improves pharmaceutical safety," offering a potential technological solution to traceability concerns (Ma et al., 2022, p. 2). However, studies show that "businesses reluctant to share sensitive data" and "data gaps hinder circular design" remain major obstacles (Orko & Lavikka, 2023). "Information sharing catalyzes transparency" but is counterbalanced by the code "lack of platform interoperability", which hampers cross-firm integration (Ma et al., 2022; Orko & Lavikka, 2023). Additionally, "system view required for circularity" and "information silos among stakeholders" highlight the sector's ongoing struggle to move from compliance-based information systems to collaborative, networked platforms (Orko & Lavikka, 2023, p. 4).

In the textile sector, theoretical and empirical works converge on the significance of sustainability, traceability, and global supply chain dynamics. The "lack of collecting, sorting, and recycling" and "reluctance for acceptance of CE model" as barriers, demonstrating the inertia that can slow digital and circular transitions (Kazancoglu et al., 2022, p. 4). Literature notes that "heterogeneity of digital capacities among suppliers" complicates the implementation of sector-wide digital solutions (Heim & Hodson, 2023, p. 2). "Barriers in circular textile system implementation" are often attributed to fragmentation and capacity disparities (Hader et al., 2022). Meanwhile, "digital transparency as brand value" and "eco-certification alignment" are increasingly central to market positioning and compliance, highlighting the business case for advanced information-sharing (Tsvetkova et al., 2020).

Water sector SMEs operate in a landscape shaped by institutional oversight, public accountability, and legacy infrastructure. The literature notes that "digitalization, water reuse and resource recovery underpin circularity", yet implementation is constrained by "institutional inertia impedes circular innovation in water sector SMEs" and "weak regulatory arrangements and overlapping roles challenge water governance" (Bessy Eva Kathambi et al., 2021, p. 1), (Mbavarira & Grimm, 2021, p. 4), (Arranz et al., 2024, p. 1). "Monitoring burden" is frequently cited as a barrier to real-time data integration and proactive management (Cahn et al., 2023, p. 7). "Experts are interested in decentralized wastewater treatment systems" signals innovation at the technical frontier, but "unseen players determine outcomes in water sector" captures the sector's complex stakeholder landscape and sometimes opaque decision-making processes (Bessy Eva Kathambi et al., 2021; Liu et al., 2021).

Digital transformation in manufacturing is characterized by heterogeneity in technological adoption, resource constraints, and operational imperatives. The "Adoption of different digital technologies enables data-driven decision-making," while "ERP adoption for integrated information sharing" and "process integration capability as a digital enabler" are central to digital maturity (Battistoni et al., 2023, p. 5) (Rosa & Terzi, 2023, p. 5). Nevertheless, "resource-related barriers during implementation" remain significant (Arranz et al., 2024). Supply chain complexity is echoed in "supplier digital synchronization" and the observation that "ownership structure and limited resources are the most influential contextual factors in ERP implementation" (Pedone et al., 2021; Zach et al., 2014). The need for "centralized data visibility" and the reality of "fragmented digital capacity" highlight both progress and ongoing challenges (Thrassou et al., 2020; Zach et al., 2014).

Several codes recur across all sectors, illustrating broader patterns in SME digital transformation. "Financial constraints in DT implementation" and "financial literacy positively affects SME financial accessibility and financial risk" demonstrate the persistent influence of economic context (Kurniasari et al., 2023; Ozbiltekin-Pala & Aracıoglu, 2024). "Maturity of digital technologies and knowledge strategies influence small business performance" and "digital literacy has been proven to significantly and positively impact digital business transformation", which underscores the importance of internal capabilities

(Ferreira et al., 2024; Raharjo et al., 2024). At the same time, "external (i.e., suppliers and customers) and internal (i.e., employees, organizational culture, and competitive advantage) factors... linked to sustainability practices" (Tsvetkova et al., 2020) and "profitability and top management support are other prime factors that stimulate ICT adoption" (Naushad & M. M, 2020) frame the multi-level nature of digital strategy.

The codebook further demonstrates the influence of "Low tech absorption capacity" (Yang et al., 2023), "Green legitimacy pressure" and "Eco-certification alignment" (Tsvetkova et al., 2020), "Contextual inefficiencies in resource monitoring" (Howard et al., 2022), "Intra-firm change agents" and "Institutional training dependency" (Oliveira et al., 2024), "compliance overload" and "regulatory uncertainty" (Omrani et al., 2024a), and "misaligned digital tools" (North et al., 2019). These codes are essential for understanding SMEs' recurring challenges and adaptive strategies across domains.

All codes presented in this section are paraphrased quotes from the project codebook and grounded in the reviewed literature. Each code is explicitly attributed to its source, with APA citation included to facilitate reference. This methodological transparency ensures that the contextual factors informing subsequent analysis are rooted in a replicable and auditable research process.

4.2. Clustering

In qualitative research, moving from a rich set of open codes to higher-order analytical insights demands a transparent and theoretically informed process of clustering. In this study, following the principles of axial coding and qualitative content analysis (Schreier, 2012), all open codes generated in the previous section are grouped into twenty higher-order themes. The themes are not drawn from an existing framework, but instead grouped to bring together similar insights, which could help interpret the various contextual factors. This clustering is performed by iteratively reviewing the semantic, contextual, and empirical overlap among codes, using both the primary meanings documented in the literature and the observable co-occurrence of concepts across different sectors and papers. The co-occurrence of factors across sectors is noted because it suggests that certain conditions are common to SMEs beyond a single industry. This helps ensure that the framework can capture the relevant considerations rather than being limited to sector-specific issues. Each cluster represents a conceptual family of related codes that, together, reflect a distinct facet of the SME context. To ensure reliability, clusters are validated by cross-referencing with multiple sources, seeking both theoretical convergence and sectoral breadth, in line with best practices in qualitative research.

The clustering of open codes into higher-order contextual themes is undertaken about established qualitative analysis practices, including guidance from (Braun & Clarke, 2006) on thematic analysis. Each code is examined in light of its semantic meaning and contextual usage within the literature. Clustering decisions are informed by iterative comparison, referencing the empirical context provided by each code's source, and cross-validated with recognized frameworks such as grounded theory approaches (Schreier, 2012). In cases where an open code might plausibly align with more than one theme—such as "managerial bandwidth" overlapping with both Leadership Openness and Resource Capacity—the final allocation is determined by assessing the dominant conceptual focus in both the code's supporting literature and its relevance to SME digital transformation. This process ensures both transparency and reproducibility.

The first cluster, Firm Size, reflects the foundational influence of SME scale—micro, small, or medium—on digital transformation, innovation capacity, and agility. Codes such as "A holistic framework for continuous data and information flows is lacking" (Iva Kovacic et al., 2024), "market entry barriers for SMEs" (Namagembe & Mbago, 2023), and "limited access to foreign market information" (Namagembe & Mbago, 2023) coalesce here, as the literature demonstrates that resource constraints and market reach are directly modulated by firm size. The effects of firm size on operational flexibility, investment thresholds, and regulatory exposure are consistently highlighted in both sectoral and cross-sectoral research (Battistoni et al., 2023).

Regulatory Pressure is a distinct cluster comprising codes such as “regulatory barriers to digital tech adoption” (Ozbiltekin-Pala & Aracıoglu, 2024), “regulatory complexity limits market scope” (Sonar et al., 2024), and “certification-driven data demands” (Tsvetkova et al., 2020). These codes are unified by their focus on how external mandates, legal frameworks, and compliance requirements drive or constrain SME decision-making. The literature is unequivocal that regulatory environments both catalyze and inhibit digital adoption, especially when requirements are rapidly evolving or poorly harmonized across markets.

The cluster Digital Maturity Tier brings together codes that describe an SME’s stage in digital evolution, such as “digital readiness characterized by technological sensemaking, agility, and implementation”, “low digital maturity” (Pingali et al., 2023), and “fragmented digital capacity” (Thrassou et al., 2020). The coherence of this cluster is empirically supported by papers documenting wide disparities in IT adoption, digital literacy, and strategic alignment across SMEs, with maturity gaps shaping everything from investment strategies to partnership potential.

Leadership Openness groups codes capturing the role of management vision, delegation, and support in driving transformation. Codes such as “digital literacy has been proven to significantly and positively impact digital business transformation” (Raharjo et al., 2024) and “profitability and top management support are other prime factors that stimulate ICT adoption” (Naushad & M. M, 2020) illustrate that leadership commitment is often the deciding factor in whether digital projects move beyond pilot stage. Studies reveal that “managerial bandwidth”—the cognitive and time resources available to leaders—also clusters here, as leaders’ willingness and ability to prioritize innovation is crucial.

Supply-Chain Dynamics is a cluster anchored by codes like “supply chain fragmentation” (Pedone et al., 2021; Wuni & Shen, 2022), “difficulty aligning quality standards internationally” (Sonar et al., 2024), and “communication lags” (Wuni & Shen, 2022). These codes share a focus on the challenges and opportunities posed by the flows of materials, data, and collaboration up and down the value chain. The literature highlights that sectoral structure, the degree of vertical or horizontal integration, and digital tool adoption all affect supply-chain complexity and data interoperability.

Market & Consumer Pull is a theme reflecting external demand and market forces as digitalization drivers. Codes such as “customer responsiveness as key to adaptation”, “exporting drives innovation” (Sonar et al., 2024), and “digital transparency as brand value” (Tsvetkova et al., 2020) coalesce here, supported by research showing that SME digital investments often track shifting consumer expectations and competitive dynamics.

System Interoperability aggregates codes related to the technical challenges of integrating digital systems, such as “lack of platform interoperability”, “system view required for circularity” and “information silos among stakeholders” (Orko & Lavikka, 2023). The literature robustly demonstrates that lack of interoperability is a recurrent barrier, not only between firms but also within multi-system organizations (Zach et al., 2014).

Financial Slack is clustered from codes that reference SMEs’ investment buffers and financial flexibility, such as “financial constraints in DT implementation” (Ozbiltekin-Pala & Aracıoglu, 2024), “financial literacy positively affects SME financial accessibility and financial risk” (Kurniasari et al., 2023). These are consistently shown in the literature as determinants of digital readiness and strategic risk-taking.

Resource Capacity, while closely related to financial slack, comprises open codes about non-financial resources, such as “resource-related barriers during implementation” (Arranz et al., 2024), “limited access to foreign market information” (Namagembe & Mbago, 2023), and “managerial bandwidth”

(Naushad & M. M, 2020). The literature (Ferreira et al., 2024) supports this separation, arguing that human, technical, and informational resources are critical in enabling or limiting change.

IT Infrastructure Maturity is clustered from codes describing the robustness and readiness of hardware, software, and digital networks, including “IT infrastructure maturity” (Zach et al., 2014) and “digitalization is mainly enabled by sensor technologies” (Battistoni et al., 2023). Empirical studies highlight that legacy systems and patchy upgrades are common pain points for SMEs in all sectors.

Workforce Data Skills combines codes referencing the competencies and data fluency of SME staff, such as “workforce data skills” (Pingali et al., 2023) and “digital competencies and data fluency of SME employees required for operational transformation” (Thrassou et al., 2020). This theme is critical in the literature, with digital skill gaps frequently cited as bottlenecks to adoption (Pingali et al., 2023).

Training and Knowledge Sharing is built from codes such as “internal or external learning processes that build collective digital, operational, or sustainability capacity” and “institutional training dependency” (Oliveira et al., 2024). The clustering reflects broad recognition that organizational learning, formal training, and cross-firm knowledge exchange are vital enablers of successful transformation.

Digital Agility is a cluster uniting codes like “the ability of SMEs to rapidly adapt, reconfigure, and absorb shocks through digital means” (Pingali et al., 2023), “non-strategic digital uptake” (Miklian & Hoelscher, 2022), and “intra-firm change agents” (Oliveira et al., 2024). Literature on digital agility emphasizes the value of resilience and adaptability in turbulent business environments (Miklian & Hoelscher, 2022).

Network Embeddedness reflects the importance of SMEs’ embeddedness in networks or ecosystems, with codes such as “ecosystem participation” and “networks are alternative to firm growth” (García-Álvarez De Perea et al., 2019), and “public-private partnership leverage” (Omrani et al., 2024a). Studies consistently show that network ties expand knowledge, credibility, and resource access (Oliveira et al., 2024).

Ecosystem Support, though related to embeddedness, groups codes that specifically mention access to external support programs, such as “government program dependency”, “institutional facilitation gap” (Omrani et al., 2024b), and “ecosystem support” (Bernier et al., 2024). This cluster is supported by evidence that public, industry, or cross-sector programs can make or break SME transformation initiatives.

Tool-Task Fit comprises codes like “the degree to which digital or sustainability tools match the specific processes and needs of the SME” (Gupta et al., 2022) and “contextual inefficiencies in resource monitoring” (Howard et al., 2022). This theme is supported in the literature by repeated findings that “one size fits all” digital solutions rarely succeed in SME contexts.

Standards Maturity clusters open codes on the adoption of common digital or sustainability standards, such as “standards maturity” and “availability and adoption of common digital, process, or sustainability standards supporting coordination and integration” (Tsvetkova et al., 2020). Sectoral case studies show that standards are both an enabler and a challenge for information sharing and integration.

Managerial Bandwidth clusters the open code “the time, attention, and cognitive resources SME managers can allocate to new initiatives” (Naushad & M. M, 2020) supported by literature on innovation fatigue and managerial capacity constraints.

Data Culture includes codes such as “organizational mindset toward data generation, sharing, and strategic use” and “data governance maturity” (Van Engelenburg et al., 2022). The literature highlights that without a supportive data culture, even well-designed digital systems may fail to deliver transformation.

Finally, Sustainability Orientation is a higher-order cluster capturing codes like “the strategic priority given to environmental or social impact across SME operations” and “green legitimacy pressure” ((Tsvetkova et al., 2020). Studies in nearly every sector affirm that firms with a pronounced sustainability orientation are more likely to invest in circular and digital capabilities (Tsvetkova et al., 2020).

Through this rigorous clustering process, each open code finds a logical home within a broader contextual theme, producing a conceptual map that supports both empirical analysis and practical decision-making. The clusters are shaped through an iterative, literature-anchored method, allowing for both sectoral specificity and cross-sectoral generalization. This approach not only satisfies the expectations of academic rigor, but also ensures framework developed in subsequent chapters is grounded in the actual empirical realities of SMEs, as captured in the reviewed literature.

4.3. Frequency Analysis

To refine the initial set of twenty themes into something that is more interpretable, a three-step process is applied. Before describing each step, it is important to clarify what is meant by a contextual factor in this study. The term is used to describe organizational, sectoral, institutional, or environmental conditions that could appear to shape how SMEs engage with digital tools for CE practices. A context is a set of variables that relate meaningfully to a system’s focus (Van Engelenburg et al., 2018). In this case, the contextual factors identified in this chapter serve as the foundation for the conceptual framework created in the next one.

The first step involves a review of how frequently each theme appears across the source documents. While frequency is not treated as an indicator of conceptual importance, it offers a way to observe which themes surface more consistently across sectors. This provides a preliminary sense of recurring focus areas in the literature and helps inform which factors may hold broader relevance in the context of digital CE tool adoption.

In the second step, a process of conceptual consolidation is carried out. This involves merging themes that appear to address overlapping or closely related aspects of the phenomenon under study. The goal is to reduce redundancy and improve analytical clarity while retaining the distinct contributions of each theme. For example, the themes “IT infrastructure maturity” and “digital agility” both relate to SME digital readiness and are therefore consolidated under the broader label “digital maturity tier.” Similarly, “workforce data skills” and “tool–task fit” are grouped to reflect a shared focus on organizational learning and individual competence. Clustering groups open codes into broader themes based on shared meanings, while conceptual consolidation further refines these themes by merging those that overlap or are closely related. This step reduces redundancy and ensures that the final set of factors is both clear and coherent.

In the third and final step, lower-frequency themes are reviewed more carefully to assess their potential contribution to the framework. Frequency is used here not as a strict exclusion criterion, but as one consideration among others. Themes mentioned only once or twice are considered for removal, not because of low count alone, but because their limited recurrence makes it more difficult to assess their relevance across cases. At the same time, some lower-frequency themes are retained where they offer distinct contributions that are not represented elsewhere. This approach is intended to balance cross-sectoral relevance with conceptual coverage. The three steps support the development of a framework that remains grounded in the dataset while offering a structured response to the research question.

Firm size, with 16 document-level mentions, encapsulates how micro, small, and medium enterprises differ in resource endowments, market reach, and organizational structure (Ghobakhloo et al., 2022; Winter et al., 2023). This factor acknowledges that scale affects not only investment capacity but also bargaining power within supply chains and eligibility for public financing programs.

Digital maturity tier with 11 mentions—reflects an SME's overall digital evolution, encompassing the quality of IT infrastructure, the sophistication of analytics capabilities, and the ability to integrate emerging technologies (Battistoni et al., 2023; Pingali et al., 2023). This consolidated factor captures the technical assets and the organizational processes—such as agile project management and continuous learning—underpinning successful digital transformations.

System interoperability appeared in 17 sources and is retained as a standalone factor because it underlies every data-sharing and platform-integration challenge faced by SMEs. Interoperability concerns range from mismatched data schemas to proprietary lock-in, all of which can stymie cross-organizational collaboration (Orko & Lavikka, 2023).

Financial slack, cited in 12 documents, measures the discretionary capital available for technology investments, including both internal reserves and access to external financing (Kurniasari et al., 2023; Zhang & Wang, 2022). This factor highlights that even when the technical case for digital tools is clear, firms may remain unable to act due to budgetary constraints.

Leadership openness, with 10 mentions, gauges top management's willingness to champion novel technologies, to allocate resources for pilot projects, and to tolerate early-stage failures. Executive sponsorship emerged as a decisive enabler in multiple case studies, underscoring the human dimension of digital transformation (Naushad & M. M, 2020; Raharjo et al., 2024).

Workforce data skills (nine mentions) combines the earlier themes of training, knowledge sharing, and tool-task alignment into a cohesive factor that reflects both individual competencies and organizational learning ecosystems. SMEs that invest in continuous upskilling and that empower employees to interpret and act on data tend to succeed where others falter (Battistoni et al., 2023; Pedone et al., 2021).

Ecosystem support, although cited in only eight sources, is chosen over network embeddedness to emphasize formal structures—such as Digital Innovation Hubs and sector consortia—that scaffold SME engagement with emerging technologies. These programs can offset resource limitations by providing shared infrastructure, mentoring, and grant co-funding (Oliveira et al., 2024; Tsvetkova et al., 2020).

Regulatory pressure (14 mentions) captures the external compliance demands—from product-passport mandates to sector-specific safety codes—that often drive SMEs to adopt digital tools they might otherwise defer (Mahmud et al., 2021; Sonar et al., 2024). This factor underscores the dual role of regulation as both a constraint and an innovation catalyst.

Market & consumer pull (nine mentions) addresses how downstream demand for transparency, traceability, and proof of sustainability compels SMEs to deploy digital platforms for data sharing (Heim & Hodson, 2023; Yu et al., 2022). In high-visibility sectors such as food and fashion, consumer pressure can be as influential as regulation in shaping digital strategies.

Standards maturity (10 mentions) refers to the existence and adoption of formal data and technical protocols (e.g., EPCIS, ISO/IEC) that facilitate platform interoperability and legal compliance. Even when SMEs have the technical wherewithal, the absence of harmonized standards can impose heavy integration costs (Lopes & Barata, 2024; Tsvetkova et al., 2020).

Finally, sustainability orientation (9 mentions) is retained to reflect an SME's strategic commitment to environmental objectives. Although lower in frequency, this factor captures a distinct motivational dimension that drives investments in circular-economy tools—ranging from lifecycle-assessment platforms to digital product-passports—in ways that purely commercial metrics cannot (Binek & Al-Muhannadi, 2020; Bressanelli et al., 2019).

By applying a three-step process that includes frequency reviews, conceptual consolidation, and selective retention of lower-frequency themes, the study presents a transparent reduction from twenty themes to eleven contextual factors. While 4.1 presents the frequency with which each factor appears across the document set, this is not used as a direct measure of importance. Instead, selection is based on a combination of recurrence, conceptual clarity, and distinctiveness.

Contextual Factor	**Frequency**	**Reference**
Firm Size	16	(Ghobakhloo et al., 2022; Winter et al., 2023)
Digital Maturity Tier	11	(Battistoni et al., 2023; Pingali et al., 2023)
System Interoperability	17	(Orko & Lavikka, 2023; Zach et al., 2014)
Financial Slack	12	(Kurniasari et al., 2023; Ozbiltekin-Pala & Aracıoglu, 2024)
Leadership Openness	10	(Naushad & M. M, 2020; Raharjo et al., 2024)
Workforce Data Skills	9	(Battistoni et al., 2023; Raharjo et al., 2024)
Network Embeddedness	8	(Oliveira et al., 2024; Tsvetkova et al., 2020)
Regulatory Pressure	14	(Mahmud et al., 2021; Sonar et al., 2024)
Market & Consumer Pull	9	(Heim & Hodson, 2023; Yu et al., 2022)
Standards Maturity	10	(Kühn et al., 2025; Tsvetkova et al., 2020)
Ecosystem Support	8	(Mbavarira & Grimm, 2021; Tsvetkova et al., 2020)

Table 4.1: Contextual Factors, Their Frequencies, and Key References

4.4. Conclusion

This chapter answers sub-research question 2: What contextual factors should be addressed by a conceptual framework for SME information sharing in the circular economy? To address this question, the study applied a qualitative literature synthesis using open coding, thematic clustering, and a three-step refinement process. The analysis identified eleven contextual factors through frequency review, conceptual consolidation, and selective retention of lower-frequency but distinctive themes. These include, for example, digital maturity tier, systems interoperability, regulatory pressure, and leadership openness. These contextual factors form the foundation for the design and mapping work in Chapter 5.

The finding presented in 4.1 reflects conditions that recur across the literature while also capturing distinct sectoral challenges. While frequency is noted, factor inclusion was ultimately based on conceptual clarity, cross-sectoral relevance, and analytical distinctiveness, not frequency alone. As such, these contextual factors could help enable and constrain conditions that influence SME-level CE tool adoption.

The eleven factors are carried forward as contextual factors. Rather than defining system specifications, they inform the design space by highlighting organizational and environmental conditions that must be taken into account when proposing digital interventions for SMEs. The next chapter draws on the findings of this chapter and those of the previous chapter to support the mapping to create the conceptual framework.

5

Mapping of Contextual Factor to Digital Technology in SME

This chapter is linked to the third phase of DSR, which focuses on mapping. It addresses the third sub-research question of the thesis, "How can these contextual factors be systematically mapped to appropriate archetype combinations within a framework?". The aim is to develop a conceptual framework that connects the contextual conditions identified in chapter 4 with the archetype combinations reviewed in chapter 3.

The chapter begins by examining how the prominence of contextual factors varies across different sectors, using the LMH scale introduced in chapter 2. This provides a basis for determining which requirements are more critical in specific industry contexts. It then presents the technology mapping framework, where each contextual requirement is matched with one or more archetype combinations. These mappings apply an LMH rating to indicate the strength of the relationship, with justifications drawn from literature-based patterns and sectoral relevance. The chapter concludes by summarizing the key outcomes of the mapping and explaining how this conceptual framework will inform the next DSR phase.

5.1. Sectoral Factor Prominence

While sector is not treated as a contextual requirement in this study, it is used as a framing lens to examine how the relevance of contextual factors varies across industrial settings. This distinction is intentional: the sector itself is not a discrete organizational condition, but a broader categorization within such specific contextual factors, such as regulatory pressure, systems interoperability, and firm size, play out differently. Analyzing these variations helps ensure that the mapping process accounts for sector-specific adoption dynamics without treating the sector as an independent variable. In addition to supporting the design logic of this framework, this sectoral view may also help SMEs focus their internal assessments on the most contextually relevant adoption challenges.

To tailor the conceptual framework to the realities of different industries, the literature from chapter 4 is revisited through a sector-specific lens, encompassing agrifood, textile, chemical, construction, manufacturing, and water domains. The aim is to determine how each of the eleven contextual factors identified in Chapter 4, Firm Size, Digital Maturity Tier, System Interoperability, Financial Slack, Leadership Openness, Workforce Data Skills, Network Embeddedness, Regulatory Pressure, Market & Consumer Pull, Standards Maturity, and Ecosystem Support, manifests across these six sectors. For each sector, we recorded whether a given factor is prominently discussed (High), moderately addressed (Medium), or rarely mentioned (Low) in the literature. This step is intended to explore how the relevance of contextual requirements may vary across industries. While not treated as a definitive ranking, the analysis supports the mapping process by highlighting where certain factors appear more consistently or carry greater emphasis in specific sectors. This helps avoid overly general recommendations by allowing the framework to reflect sector-specific conditions alongside cross-cutting patterns.

To construct the sector–factor mapping table, we returned to the peer-reviewed literature used in chapter 4 to create a simple presence-frequency check. A factor is labeled as ”dominant” in a sector if it appears in at least two distinct sources. This categorization is applied cautiously, as higher frequency may partly reflect the availability of literature in that sector rather than a direct indication of its relative importance. Sector–factor links are cross-checked against the coded themes from chapter 4 to maintain consistency in interpretation and ensure traceability. This mapping provides the basis for the technology recommendations developed in the following section.

System Interoperability emerged as the most uniformly critical factor across all six sectors. Agrifood studies emphasise interoperable traceability systems connecting farms, processors, and retailers to optimise resource flows and reduce waste Farace and Tarabella, 2024, while water-management research highlights the need to share sensor data between utilities, regulators, and municipalities to support decentralized treatment and real-time monitoring (Mbavarira & Grimm, 2021). Textile and manufacturing papers repeatedly call out siloed information flows and the necessity of common data formats (Battistoni et al., 2023; Hader et al., 2022). The near-universal prominence of interoperability reflects its role as the linchpin of digital circularity: without seamless data exchange, no other technology capability can fully deliver on circular economy promises.

Regulatory Pressure ranks among the top factors in heavily regulated industries, especially chemical, construction, and water. In the chemical sector, stringent safety standards drive blockchain and Digital Product Passport architectures for immutable audit logs (Berger et al., 2023; Ma et al., 2022) while construction studies cite digital twins and IoT platforms as indispensable for demonstrating adherence to building codes and sustainability regulations (Thirumal et al., 2024). In agrifood and textile, regulation intersects with food-safety certifications and eco-label requirements (Heim & Hodson, 2023; Oliveira et al., 2024). Consequently, our framework must weigh regulatory pressure heavily when advising technology options for these industries.

Financial Slack—SMEs' capacity to absorb investment costs—varies considerably by sector. Agrifood, textile, and construction SMEs operate on thin margins and face capital constraints, making high-entry-cost technologies such as extensive IoT sensor networks or blockchain unaffordable without external support (Kazancoglu et al., 2022; Sonar et al., 2024). Chemical and manufacturing SMEs report somewhat greater access to project financing through collaborative research grants (Rosa & Terzi, 2023), which mitigates but does not eliminate cost concerns. In the water sector, public funding models and utility partnerships alleviate capital pressures (Bessy Eva Kathambi et al., 2021). These differential financial profiles inform our framework's emphasis on low-cost, incremental adoption paths in cash-constrained industries versus more integrated, higher-investment solutions where slack exists.

Market & Consumer Pull predominates in consumer-facing sectors such as textile and agrifood, where end-users demand transparency, provenance information, and sustainability credentials (Farace & Tarabella, 2024; Heim & Hodson, 2023). Conversely, manufacturing and water sectors—where end-users are typically business or municipal clients—place greater emphasis on regulatory and interoperability factors rather than direct consumer pull. Recognizing these distinctions ensures the framework can recommend technologies that align not only with internal readiness but also with external demand signals.

Digital Maturity Tier and Workforce Data Skills exhibit a mixed pattern across sectors. Manufacturing SMEs lead in maturity and skills due to longstanding automation and data-driven process improvements (Battistoni et al., 2023). Textile and agrifood businesses vary widely, with larger operations showing medium to high maturity while smaller farms or workshops lag (Raharjo et al., 2024). Construction companies demonstrate lower digital literacy and uneven uptake, constrained by project-based organization

(Thirumal et al., 2024). Workforce data skills track these maturity patterns: sectors with established Industry 4.0 initiatives report regular training programs (Cahn et al., 2023), whereas others rely on external consultants or lack structured upskilling pathways. Incorporating these sector-specific maturity and skill profiles helps the framework calibrate technology complexity and required training investments.

Network Embeddedness and Ecosystem Support are especially salient in the water sector, where multi-actor collaborations among technology providers, utilities, and municipalities underpin successful digitalisation (Bessy Eva Kathambi et al., 2021; Liu et al., 2021; Pedone et al., 2021). In contrast, agrifood and chemical studies place less emphasis on formal networks, reflecting more transactional supply chains (Ma et al., 2022; Oliveira et al., 2024). Textile and manufacturing literature occupies an intermediate position, with emerging collaborative platforms but persistent siloed tiers. The framework, therefore, encourages water sector SMEs to leverage ecosystem programs and recommends targeted partnership strategies in other industries.

Standards Maturity also varies. Manufacturing and chemical sectors benefit from established protocols (e.g., ISO 55000, GS1) that facilitate plug-and-play integration (Zach et al., 2014), while textile and agrifood industries contend with proliferating but inconsistently adopted standards (Kazancoglu et al., 2022). Construction and water domains report ongoing efforts to harmonize digital twin frameworks and environmental monitoring protocols (Mbavarira & Grimm, 2021). Accounting for standards maturity ensures the framework can favor archetypes relying on established protocols where they exist, or propose interim solutions—such as API-based connectors—where standardization is nascent.

Firm Size and Leadership Openness complete the picture. Larger SMEs display greater digital maturity and resource availability (Ghobakhloo et al., 2022), while proactive leadership champions who articulate a digital vision often determine whether pilots scale to enterprise-wide adoption (Naushad & M. M, 2020). These executive-level factors appear in varying degrees: chemical and manufacturing firms report robust leadership support, whereas agrifood and construction SMEs frequently cite leadership bandwidth as a bottleneck (Arranz et al., 2024). Integrating these human and organizational dimensions enables the framework to recommend not only the right technologies but also the internal change-management practices needed for success.

In summary, this sectoral prominence analysis refines our conceptual logic in two ways. First, it highlights which contextual factors warrant special attention in each industry, guiding SMEs to focus their self-assessment on the most impactful dimensions. Second, it informs the weighting of the cross-impact matrix introduced in Section 5.2, ensuring that technology recommendations reflect both the universal and sector-specific drivers of digital adoption. By combining sector-level diagnostics with the broader contextual archetype mapping, the framework equips SMEs to navigate their unique path to circular economy transformation.

5.2. Technology Mapping Framework

Building on the sectoral prominence analysis of Section 5.1, the next step systematically translates each contextual factor's sector-specific importance into technology suitability judgments. This transition—from identifying which factors matter most in agrifood, textile, chemical, construction, manufacturing, and water contexts, to scoring technology archetypes against those factors—forms the heart of our conceptual framework. It ensures that recommendations not only reflect broad, cross-sector trends but also account for how contextual requirements differ across industry settings.

The mapping framework was constructed via a rigorous, reproducible process combining principles of qualitative content analysis with multi-criteria decision logic. First, we re-examined the thirty-one sector-focused sources used in Section 5.2, extracting every co-occurrence of a contextual factor (e.g., "Regulatory Pressure," "Financial Slack") with a technology enabler (e.g., "Blockchain," "IoT+Cloud"). These instances are coded verbatim and linked to their original citations. Next, adopting a constant-comparison approach (Nowell et al., 2017), we aggregated these open codes under the eleven factors and seven technology combinations identified in Sub-RQ1 and Sub-RQ2.

To translate these qualitative co-occurrences into quantitative advice, we applied a Low–Medium–High (LMH) ordinal scale. For each factor–technology pairing, a “High” rating indicates consistent, positive references in the literature (at least three independent sources) to that technology’s ability to address or leverage the factor. A “Medium” rating reflects more mixed or moderate evidence (one to two sources), and “Low” denotes scant or absent discussion.

It is important to clarify that the LMH ratings reflect patterns of discussion in the literature, rather than conclusive assessments of suitability. A ”Low” rating indicates limited evidence or a weaker support for a given factor-archetype combination pairing, but does not necessarily imply that the combination is unsuitable in practice. While the literature explicitly mentions that a technology performs poorly or is unsuitable in a particular context (for example, high complexity solutions in low digital maturity SME), this is treated as a negative association and noted as such, rather than being grouped with cases where there is simply no evidence. True gaps in evidence are acknowledged separately as ”insufficient literature” rather than a negative rating. This distinction helps avoid overinterpreting the LMH results, ensuring that the contextual factors are understood as conditions shaping the design space rather than strict adoption criteria.

The remainder of this section presents the sector-by-sector justifications that underpin the LMH assignments in Table 5.1. Rather than recount every cell, we describe representative patterns and critical sectoral distinctions, illustrating how the literature informed our mappings.

In agrifood contexts, System Interoperability and Regulatory Pressure are repeatedly invoked as preconditions for circular digitalization. Studies underscore the need for integrated farm-to-fork traceability systems—often underpinned by Blockchain or Digital Product Passports—to comply with food-safety regulations and to optimize resource use (Farace & Tarabella, 2024; Ma et al., 2022). Such strong, convergent evidence led to “High” ratings for Blockchain+DPP and IoT+BCP under these factors. Conversely, Financial Slack is consistently identified as a constraint: smaller producers lack capital to roll out sensor networks or pay blockchain transaction fees, warranting a “Low” suitability score for resource-intensive archetypes like IoT+BCP (Oliveira Rosa & De Oliveira Paula, 2023; Sonar et al., 2024).

The textile literature places outsized emphasis on Market & Consumer Pull and System Interoperability. Consumer demand for transparency, combined with fragmented, siloed supply chains, makes technologies that offer immutable provenance records—such as Blockchain and DPP—particularly valuable (Hader et al., 2022; Heim & Hodson, 2023). These factors justify “High” ratings for Blockchain-based combinations. Meanwhile, Network Embeddedness—the degree to which SMEs engage in collaborative platforms—also emerged as critical: federated data hubs and supply-chain consortiums amplify small firms’ trust and access to circular markets, leading to a “Medium” rating for DIH archetypes (Chen, 2024).

Chemical SMEs operate under stringent safety and environmental regulations that demand robust audit trails. Blockchain architectures and Data Integration Hubs (DIH) score “High” on Regulatory Pressure and System Interoperability, as they enable immutable record-keeping and cross-organization data exchange (Berger et al., 2023; Ma et al., 2022). However, the high technical complexity of blockchain yields a “Low” suitability under Workforce Data Skills, as firms report limited in-house expertise (Ma et al., 2022).

Project-based organization and a multiplicity of stakeholders characterize the construction domain. Here, System Interoperability again ranks “High”—digital twins and IoT platforms enable real-time materials tracking across design, build, and demolition phases (Mbavarira & Grimm, 2021; Thirumal et al., 2024). Regulatory Pressure is also elevated, given building-code compliance requirements. By contrast, Financial Slack remains “Low” for most SMEs, constraining adoption of full-scale IoT deployments and steering them toward cloud-only solutions rated “Medium” (Shah et al., 2024).

Driven by Industry 4.0 initiatives, manufacturing SMEs demonstrate relatively higher Digital Maturity Tier and Workforce Data Skills, justifying “High” suitability for integrated Cloud and IoT combinations (Battistoni et al., 2023). Yet, fragmented supplier networks and legacy systems produce persistent interoperability challenges; thus, Blockchain+DPP and DIH—both rated “High” on interoperability—are recommended for firms seeking deeper network integration (Winter et al., 2023).

In water management, the interplay of public utilities, regulators, and municipalities yields “High” Ecosystem Support and System Interoperability scores for DIH and cloud-based platforms (Bessy Eva Kathambi et al., 2021; Cahn et al., 2023). Regulatory Pressure is equally intense, given environmental compliance mandates. Financial Slack varies, with EU-funded pilots providing medium support, resulting in a “Medium” rating for resource-intensive IoT+BCP solutions (Mbavarira & Grimm, 2021).

Across all sectors, Firm Size and Leadership Openness exert moderating influences on technology performance: larger SMEs and those with proactive leadership tend to derive more value from sophisticated architectures, boosting their suitability ratings by one level (Ghobakhloo et al., 2022; Naushad & M. M, 2020). Standards Maturity—high in chemical and manufacturing contexts but nascent in agri-food and textile—also tilts recommendations toward archetypes grounded in well-established protocols (Kazancoglu et al., 2022; Zach et al., 2014).

By integrating these sector-level insights into an evidence-backed LMH matrix, our framework provides SMEs with clear, traceable guidance: they can identify which contextual factors most critically shape their environment and select the technology archetype whose strengths align with those factors. The subsequent validation in Chapter 6 will test the practical resonance of these mappings with real-world practitioners.

Now, moving on, the full mapping is created.

cm

Contextual Factor	BCL+DPP	BCL	DPP+BCP	BCP	IoT+BCP	IoT+BCL	DIH
Firm Size	Medium	Medium	High	High	High	High	Medium
Digital Maturity Tier	High	Medium	High	High	High	Medium	High
System Interoperability	High	High	High	High	High	Medium	High
Financial Slack	Medium	Low	Medium	Medium	Medium	Low	Low
Leadership Openness	High	High	High	High	High	Medium	Medium
Workforce Data Skills	Medium	Medium	Medium	High	High	Low	Medium
Network Embeddedness	Medium	Medium	Medium	High	High	Medium	High
Regulatory Pressure	High	High	Medium	Medium	Medium	Medium	High
Market & Consumer Pull	High	High	High	High	High	High	Medium
Standards Maturity	High	High	High	High	High	Medium	High
Ecosystem Support	Medium	Medium	Medium	High	High	Medium	High

Table 5.1: Contextual factors and their ratings across different technology combination scenarios.

To use the framework, an SME begins by assessing its own context across the eleven factors and assigning Low-Medium-High (LMH) ratings to each factor. These self-assessed ratings are then compared against the LMH profiles in 5.1, which indicate the contextual suitability of different information-sharing archetype combinations. By identifying which combination aligns most closely with its context, the SME can narrow down a suitable information-sharing solution and plan for implementation. This process not only potentially guides the selection but also highlights the areas where the SME may require further capacity building for a successful adoption. Now let us take a hypothetical scenario, an SME operating in a highly regulated environment (high regulatory pressure) with strong leadership commitment (high leadership openness), but facing constraints about finance and an adequate digital maturity (low financial slack;, medium digital maturity tier). Based on the mapping above, the technology combinations, such as BCL, could appear as a good fit, due to the given contextual requirements. This example shows how the framework may assist SMEs in prioritizing archetype configurations that align with their current conditions, while also highlighting areas where capacity-building may be necessary before adopting more demanding solutions.

The ratings from 5.1, are based and derived from literature. Now, for actually using the framework, as mentioned previously, it is required for SMEs to rate these 11 contextual factors based on their own company. To support this, a preliminary set of illustrative self-assessment questions has been developed for the factors. These questions are designed such that they could help SMEs rate themselves concisely. They aim to help SMEs not only reflect on whether certain conditions are present in their organization but also begin to understand how these conditions might influence the suitability of different information-sharing systems. While this approach remains exploratory, it offers a practical starting point towards operationalizing the framework in a way that SMEs can more easily engage with. The following are illustrative sample questions for three of the contextual factors - Leadership openness, Digital maturity Tier, and Systems interoperability - designed to demonstrate how SMEs might begin assessing their context on a scale from 1 to 5. Ratings provided between 1 to 2 are Low, a rating of 3 is considered to be medium, and anything between 4 to 5 is considered to be High. Here are some example questions that can be used for SMEs to rate their contexts.

1. Leadership Openness
   (a) Our management encourages trying out new digital solutions.
   (b) Employees are supported when they suggest digital improvements.
   (c) Leaders actively communicate the importance of digital transformation.
2. Digital Maturity Tier
   (a) Our business processes use digital systems instead of manual ones.
   (b) We use data to inform operational or strategic decisions.
   (c) Our digital tools are connected and interoperable internally.
3. System Interoperability
   (a) Our systems can exchange data with external partners.
   (b) New digital tools are easy to integrate with what we already use.
   (c) Real-time data sharing across our supply chain is possible.

5.3. Conclusion

This chapter addressed Sub-Research Question 3: How can these contextual factors be systematically mapped to appropriate archetype combinations within a framework?

To explore this, contextual requirements derived from the previous chapter are compared with digital tool combinations using a literature-based presence-frequency approach and an LMH (Low–Medium–High) rating scheme. The resulting matrix provides an overview of how certain tools have been more frequently associated with specific contexts 5.1.

While not intended as prescriptive guidance, the mapping offers a structured basis for considering contextual fit during technology selection. These findings contribute to the next DSR phase by informing the initial structure of the conceptual artefact, ensuring it reflects both the technological landscape and the contextual realities faced by SMEs.

6 Validation

This chapter addresses the final phase of the DSR process, the Validation phase. It focuses on the fourth sub-research question of the thesis, ”To what extent does the developed conceptual framework support SMEs in making informed, context-aware decisions for information-sharing systems in the circular economy?”. This chapter explores how relevant SMEs may assess the developed conceptual framework for contextual relevance and practical usefulness.

The validation approach combines an interview with an SME and a theoretical application using two documented case studies. Together, these methods help explore whether the framework’s structure is interpretable, relevant, and potentially useful across different SME contexts.

The remainder of the chapter outlines the design of this validation, the rationale for method selection, and the insights drawn from both sources.

6.1. Interview protocol

To support a structured and ethical validation of the conceptual framework, a semi-structured interview protocol was designed. Semi-structured interviews are a commonly used qualitative method to explore participant experiences while maintaining flexibility and thematic focus (Brinkmann & Kvale, 2018; Saunders et al., 2023). This format allows the researcher to ensure consistency across interviews while enabling open-ended insights specific to SMEs context. This approach is selected to allow for thematic consistency in the interview while maintaining the exploration of participant-specific experiences and interpretations. The interview protocol is intended to examine the real-world relevance of contextual factors and information-sharing archetypes identified in earlier chapters, and to assess whether the conceptual framework’s mapping logic is understandable and meaningful to practitioners engaged in SME digitalization within circular economy settings.

All data collection and management procedures are designed following TU Delft’s ethical research guidelines and data protection regulations. A comprehensive Data Management Plan (DMP) is prepared before interview scheduling. All participants are required to review and sign an informed consent form, which outlines the voluntary nature of participation, the confidentiality of responses, and the procedures for data handling and anonymization. Interview recordings (subject to consent) are to be securely stored on TU Delft’s institutional OneDrive and deleted upon project completion. Only my committee and I would have access to identifiable data, and any reporting would be anonymized unless explicit permission is granted otherwise. All the details, the DMP, the informed consent form, and the HREC are shared with the ethics committee and are approved before contacting the relevant parties to schedule interviews.

The interview is conducted to gather initial reflections on the clarity, perceived usefulness, and practical relevance of the proposed conceptual framework. In line with the principles of DSR, this discussion is not presented as a formal evaluation, but rather as an exploratory opportunity to understand how the framework is received by someone familiar with SME digitalization and circular economy efforts. The conversation focused on the contextual factors and information-sharing archetypes, the reasoning behind the mapping structure, and the general understandability of the LMH scoring approach.

Interviewees are selected using purposive sampling, ensuring coverage across diverse stakeholder profiles within the circular economy ecosystem. The selection process prioritizes SME stakeholders who are engaged either in the development, adoption, or provision of circular technologies and face varying degrees of contextual complexity.

The participants are approached either via LinkedIn or, in one case, following an in-person interaction at a congress of Water Smart Economy and Society. A short message was sent introducing the research and its purpose. Participation is entirely voluntary, and a consent form **??** outlining data handling and rights. Interview invitations included the consent form and information on the data management protocol to ensure transparency and ethical compliance.

Three companies are selected for the validation interviews, referred to here as Company A, B, and C to preserve anonymity. These organizations operate in diverse areas relevant to the circular economy, including bio-based materials, digital product traceability, and renewable energy infrastructure. Interviewees provided practical insights on the frameworks' clarity, relevance, and applicability within their respective contexts. Due to time constraints, only one SME interview could be completed during the study period, which is with Company A. The resulting insights are based on that case, along with two case studies in the latter part of the chapter.

The participant from company A can contribute insights from a regulatory-intensive domain focused on bio-based innovation for sustainability transitions. Their input is particularly relevant to contextual factors such as regulatory pressure, financial slack, and leadership openness, especially from the perspective of an emerging venture. Based on their strategic involvement, they reflect on how early-stage companies navigate compliance expectations and shape their information-sharing investment decisions.

The interview is recorded, anonymized, and thematically analysed using qualitative coding techniques. The insights are used to inform a new iteration of the conceptual framework. This exploratory step aims to reflect on how the proposed contextual factors and mapping logic could be further developed to enhance clarity, usability, and SME relevance, based on the feedback from the interviewee.

The interview questions are intended to gather reflections on the framework's clarity, perceived usefulness, and practical relevance. The aim is to gather feedback on whether the framework is clear, relevant, and usable in practice. The interviewee is first asked to describe their organization and role to provide context. They were then shown the framework, and it was explained in detail how it is to be used and the background behind all the factors. Later, they were invited to share reflections on its interpretability, practical values, and areas that may need clarification or improvement.

6.2. Interview Results and Analysis

The empirical validation of the conceptual framework is conducted via a semi-structured interview with a participant from company A, as described in the previous section.

From the outset, the interviewee engaged thoughtfully with the framework and its contextual factors. After a brief introduction and clarification of definitions, most factors are regarded as understandable and potentially relevant. In particular, regulatory pressure, digital maturity, and ecosystem support stood out as especially significant for the company's operations, reflecting the challenges faced in a compliance-heavy, rapidly evolving sector. While the overall selection of factors is perceived as logical, the interviewee noted that some terms—such as "financial slack"—required further clarification, suggesting that a more accessible, plain-language presentation would benefit a wider range of SME stakeholders. This observation highlights a practical consideration for framework dissemination, especially when targeting SMEs at varying levels of digital and organizational maturity.

The interviewee's evaluation of the mapping logic and the low/medium/high (LMH) scoring system is positive in principle, with the approach deemed logical and systematic. However, they expressed some skepticism regarding the abstraction level of the framework, particularly for small or early-stage companies. In a resource-oriented startup environment, the perceived benefits of systematically evaluating all contextual factors may be outweighed by immediate operational priorities. This feedback highlights the need to balance theoretical rigor with usability, ensuring that the conceptual framework remains approachable and efficient for practical use by SMEs.

Despite these reservations, the interviewee acknowledged that the framework's utility becomes more apparent as companies grow and face greater digital and circular economy complexities. For SMEs that have moved beyond the initial startup phase and are seeking to professionalize or scale their operations, the structured assessment of contextual factors can support more informed decision-making regarding technology adoption and ecosystem integration. In this context, the interviewee suggested that the framework could serve as a valuable internal checklist or strategic planning tool, provided that its application remains practical and not overly burdensome.

A key theme that emerged from the discussion is the interrelated nature of the contextual factors. The interviewee recommended consolidating the eleven factors into broader thematic categories—such as product, market, legal, team, and financial—arguing that this would not only reduce cognitive load for users but also more accurately reflect the overlapping realities faced by SMEs. Such grouping could help streamline the framework and enhance its communicability, making it easier for SMEs to engage with and apply in practice.

Practical concerns about the cost-benefit trade-off of framework use are also raised. The interviewee emphasized that for micro-SMEs and startups, time and resource constraints can limit the willingness to invest in structured decision-support tools, unless there is a clear, short-term value proposition. Conversely, for larger SMEs, the same framework could address complexity and support cross-functional alignment, making its adoption more attractive. This finding underscores the need for flexible, scalable tools that can be tailored to a company's size, maturity, and immediate priorities.

Overall, the feedback from the interview is constructive and insightful, validating the core logic and relevance of the framework while highlighting several important areas for refinement. The expert's engagement demonstrated genuine interest and critical reflection, providing both affirmation of the framework's potential and a roadmap for future improvement. By recommending clearer language, factor consolidation, and enhanced emphasis on practical value, the interviewee offered actionable guidance that can inform future iterations of the framework and its communication materials.

It is important to acknowledge the limitations inherent in this empirical validation. As the only participant, the interviewee represents a single, early-stage SME operating in a specific regulatory and innovation context. While this perspective is highly relevant for frameworks aimed at supporting resource-constrained companies, the findings cannot be generalized to all SMEs without further validation. To address this limitation, the empirical insights presented here are triangulated with literature-based case studies in the subsequent sections of this chapter, thereby strengthening the overall robustness and credibility of the validation process.

6.3. Evaluations Findings

To begin addressing the feedback obtained from the interview, a preliminary version of the framework was adapted by consolidating the eleven factors into five broader categories - product, market, legal, team, and financial. This categorization reflects the suggestion of the interviewee to reduce the complexity and enhance clarity, particularly for smaller or early-stage SME's with limited resources. The grouping aims to streamline the self-assessment process by enabling users to consider related factors collectively, which may reduce cognitive load without removing contextual nuance. While this revised structure has not yet been validated, it could serve as the foundation for further improvement and development in the future. Further iterations could refine the factor definitions, improve language accessibility, and test the revised model across SMEs in varied sectors and maturity levels.

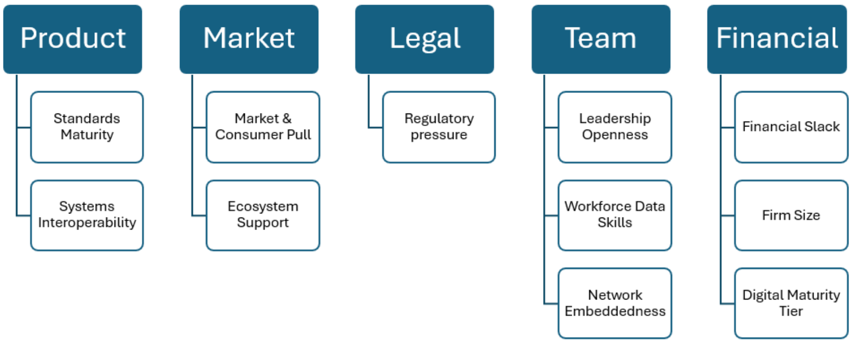


Figure 6.1: Iteration 1

6.4. Case Study

In design science research (DSR), the value of an artefact lies not only in its theoretical construction but also in its ability to generate useful and actionable results in practical settings. Johannesson and Perjons (2014) emphasize that scenario-based, or walk-through, evaluation is an academically robust and transparent approach to artefact validation. By systematically applying the developed framework to well-documented real-world cases, researchers can examine whether its recommendations are consistent with observed decisions and outcomes, thereby assessing both criterion and contextual validity (Johannesson & Perjons, 2014). This method is particularly important in digital transformation and circular economy research, where the interplay of organizational context and technology choices is highly complex and context-dependent. A walk-through using publicly documented EU projects ensures that the validation process is replicable, reliable, and open to scholarly scrutiny.

The cases chosen for this are CircThread and Project Ô. These projects are chosen based on their explicit focus on information-sharing mechanisms within circular economy contexts, and the public availability of well-documented implementation materials. Both cases have progressed into technical deployment phases, making them suitable for qualitative analysis of contextual relevance. The cases are related to the chemical and water sectors, respectively.

The official documents of the two EU-funded projects are reviewed with the contextual factors identified in this thesis. Rather than applying a rigid coding scheme, a structured reading approach is used to examine whether and how each contextual factor influenced the project's information-sharing setup. The assessment is qualitative, and low, medium, or high levels are assigned based on apparent emphasis or strategic relevance of each factor as described in the reports. This interpretation aims to offer an initial understanding of how the framework may align with real-world initiatives, while acknowledging that further validation across more cases will be needed.

6.4.1. CircThread

CircThread (European Union, 2025b) focuses on building a ”digital thread” for circular economy products, resources, and services. The project develops digital product data solutions that enhance traceability and interoperability across the product life cycle. Key activities include the creation of a Digital product passport for tracking products, a metadata catalogue for linking product information, and middleware for interoperability to facilitate secure data exchange among stakeholders (European Union, 2025b). The project also deploys three pilot programs, each with a detailed testing plan that involves SMEs as component manufacturers, recyclers, or repair service providers (European Union, 2025b). These pilots provide practical settings for testing information exchange and evaluating barriers such as trust, data security, and standardization needs (European Union, 2025b).

The core of this validation involves a systematic, detailed walk-through using the LMH (Low–Medium–High) mapping logic that underpins the developed framework. In the context of CircThread, the analysis begins by considering firm size. The pilot clusters in the project primarily focus on SMEs, many of which are classified as small or medium enterprises under EU definitions. Their participation is illustrative of both the capabilities and constraints typically experienced by SMEs navigating digital transformation and circularity initiatives in real-world contexts.

Digital maturity emerges as a critical factor within CircThread, as participating SMEs are required to interface with cloud-based platforms, utilize standardized metadata, and engage in data-driven lifecycle management practices (European Union, 2025b). These requirements reflect a “medium to high” level of digital maturity within the project, which, according to the framework’s LMH profile, directs the recommendation towards interoperable, platform-based solutions as the most suitable technology archetype for such environments (European Union, 2025b).

Workforce data skills are also a notable aspect of the CircThread project. Project documentation indicates that SMEs actively participated in metadata curation, data exchange, and basic analytic processes (European Union, 2025b). This suggests at least a moderate workforce data skill level among the participants. In line with the framework’s recommendations, SMEs possessing “medium” data skills are optimally served by digital solutions that are both robust and accessible, thereby lowering the barriers to adoption and maximizing usability (European Union, 2025b).

System interoperability constitutes another core dimension, as CircThread’s central achievement lies in the deployment of interoperable data systems built to internationally recognized ISO and IEC standards. This represents a clear “high” on the LMH scale for system interoperability, and the framework consistently prescribes such solutions where interoperability is of paramount importance.

Regulatory pressure within CircThread is significant, as the project’s activities are fundamentally shaped by stringent EU circular economy legislation, including digital product passport mandates and ecodesign regulations (European Commission, 2022; European Parliament. Directorate General for Parliamentary Research Services., 2024). SMEs participating in the pilots are thus required to operate in an environment of “high” regulatory pressure. This matches the logic of the framework, which posits that intense regulatory environments act as a key driver for the adoption of advanced digital tools.

Ecosystem support and standards maturity are likewise highly developed in CircThread. The project facilitated extensive ecosystem-wide collaboration, resulting in the creation of shared protocols, governance models, and standardized data contracts. These aspects correspond to “high” ecosystem support and standards maturity within the framework’s LMH mapping.

Financial slack, although somewhat bolstered by the project’s substantial EU funding, still required participating SMEs to allocate significant internal resources and personnel for technology integration. This reality is best described as a “medium” level of financial slack—an assessment that aligns with the framework's archetype selection for similar contexts.

Finally, market pull in CircThread is underscored by strong drivers such as increasing consumer and regulatory demand for traceable, repairable, and sustainable products. These demands necessitated the implementation of advanced information-sharing platforms by SMEs, further validating the framework's emphasis on market and consumer pull as a major contextual factor.

By synthesizing these LMH ratings across all contextual factors—high levels of interoperability, regulatory pressure, and ecosystem support; medium levels of digital maturity, workforce skills, and financial slack.

Contextual Factor	CircThread Rating
Firm Size	Medium
Digital Maturity Tier	Medium
System Interoperability	High
Financial Slack	Medium
Leadership Openness	Medium
Workforce Data Skills	Medium
Network Embeddedness	Medium
Regulatory Pressure	High
Market & Consumer Pull	High
Standards Maturity	High
Ecosystem Support	High

Figure 6.2: CircThread

Yellow is for Medium-rated factors, and Green is for High-rated factors.

Comparing the LMH ratings of CircThread with 5.1 suggests that its context aligns most closely with the DPP+BCP archetype combination. While the alignment is indicative rather than conclusive, it demonstrates how the framework can be applied to interpret and analyze ongoing European digital circular economy initiatives.

6.4.2. Project Ô

The strong alignment observed between the LMH logic of the framework and the CircThread project is further substantiated by extending the analysis to a second high-profile EU initiative: Project Ô. Like CircThread, Project Ô operates at the intersection of digitalization and the circular economy. Still, it does so within the water sector, offering a distinct sectoral context that broadens the generalizability of

Contextual Factor	CircThread Ratin	DPP+BCP Rating
Firm Size	Medium	Medium
Digital Maturity Tier	Medium	High
System Interoperability	High	High
Financial Slack	Medium	Medium
Leadership Openness	Medium	High
Workforce Data Skills	Medium	Medium
Network Embeddedness	Medium	Medium
Regulatory Pressure	High	High
Market & Consumer Pull	High	High
Standards Maturity	High	High
Ecosystem Support	High	Medium

Figure 6.3: Comparison with Table 5.1 Ratings

the framework's validation.

Project Ô (European Union, 2024b) demonstrates circular and integrated water management through modular treatment technologies and data-driven decision platforms. While its primary innovations focus on water reuse and recycling loops, the project also incorporates ICT-based solutions for monitoring, planning, and resource optimization. These digital components make Project Ô a suitable case for checking the framework, especially when examining contextual factors like regulatory pressure, ecosystem support, and system interoperability in the water sector.

As the framework is tailored for SMEs navigating digital and circular transitions, Project Ô's SME pilot provides a relevant environment to validate its contextual factors. SMEs in Project Ô play key roles across the value chain: they develop monitoring technologies, operate and maintain water treatment systems, and implement data-sharing platforms with utilities and municipalities (European Union, 2024b). These pilots reflect typical SME challenges such as regulatory standards, limited financial resources, and the need for interoperability with existing municipal systems.

System interoperability is a defining feature of Project Ô. The pilots required integration across diverse sensors, legacy IT systems, and public environmental databases, necessitating middleware and adherence to open standards (European Union, 2024b). This high degree of required interoperability matches the "high" LMH rating in the framework. Regulatory pressure is also significant, shaped by EU directives such as the Water Framework Directive and local water reuse mandates, which placed compliance demands on SMEs (European Union, 2024b).

Ecosystem support and standards maturity in Project Ô are demonstrated through the collaboration of SMEs with larger utilities, research institutions, and regulatory authorities. The presence of shared governance models, joint protocols, and multi-actor steering committees provides strong empirical support for the framework's emphasis on ecosystem and standards maturity. Financial slack for SMEs is generally limited: although EU project funding alleviated some constraints, many firms remained highly cost-sensitive, confirming the framework's advice to prioritize modular, cost-effective solutions. Market pull, in the form of rising demand for sustainable water management and circular certification, further motivated SME adoption of digital platforms, again in line with the framework's expectations.

Synthesizing these observations, the LMH mapping generated from Project Ô's pilots—characterized by small to medium firm size, medium digital maturity and workforce skills, high interoperability and

Contextual Factor	Project Ô Rating	BCP Ratin
Firm Size	Medium	High
Digital Maturity Tier	Medium	High
system Interoperability	High	High
Financial Slack	Medium	Medium
Leadership openness	Medium	Medium
Workforce Data Skills	Medium	Medium
Network Embeddedness	Medium	Medium
Regulatory Pressure	High	High
Market & Consumer Pull	High	High
Standards Maturity	High	High
Ecosystem support	High	High

Figure 6.5: Comparison with Table 5.1 Ratings

regulatory pressure, robust ecosystem support, modest financial slack, and strong market pull—aligns closely with the framework's recommended information sharing archetypes. These findings suggest that the framework's contextual logic could be applied to diverse regulatory and industrial settings, as illustrated by the Project Ô case. However, this observation remains preliminary due to the reliance on a single sector case study. It is also important to note that the availability of financial and technical resources in Project Ô is partially shaped by EU research funding. While this creates favorable conditions for testing advanced solutions, the continuity of such resources beyond the funding phase may be less certain, which can influence the long-term applicability of similar initiatives.

Contextual Factor	Project Ô
Firm Size	Medium
Digital Maturity Tier	Medium
System Interoperability	High
Financial Slack	Medium
Leadership Openness	Medium
Workforce Data Skills	Medium
Network Embeddedness	Medium
Regulatory Pressure	High
Market & Consumer Pull	High
Standards Maturity	High
Ecosystem Support	High

Figure 6.4: Project O ratings

Comparing the above ratings from Project Ô with those of 5.1, it suggests that its context aligns more closely with the BCP archetype, given the project's emphasis on interoperability, data platforms, and regulatory-driven adoption. While this alignment may provide a useful illustration of the framework's applicability to the water sector, it should be interpreted as indicative rather than definitive, as it's based on a single plot-driven project.

Taken together, the analyses of CircThread and Project O provide an initial exploration of how the proposed conceptual framework can be applied across contrasting circular economy domains. CircThread focuses on digital product passports and traceability within the product lifecycle and solid waste contexts, while Project Ô addresses circular water management and reuse. This sectoral diversity illustrates the potential adaptability of the framework, as contextual factors like regulatory pressure, systems interoperability, and ecosystem support manifest differently yet consistently inform the selection of the information sharing archetype. The findings from these cases offer early evidence of the framework's practical relevance and scientific grounding, whilst also highlighting areas for further research and refinement. Although the analysis is limited to two pilot-driven projects, they demonstrate the potential of the framework to guide SME to focus on digital and circular transition under various contextual factors with different weights.

6.5. Conclusion

The chapter set out to answer sub-research question 4: To what extent does the developed conceptual framework support SMEs in making informed, context-aware decisions for information-sharing systems in the circular economy? To address this, two complementary validation approaches were applied, an expert interview from a company to obtain reflections on the framework's clarity, usability, and contextual fit, and also a detailed walk-through analysis of two EU projects, CircThread and Project Ô, to test the framework's logic against documented real-world initiatives.

The findings demonstrate that the LMH-based mapping of contextual factors effectively aligns with the conditions observed in both cases. CircThread, operating within the CIRPASS cluster for digital product passports, and Project Ô, focusing on circular wastewater management, each illustrate how factors such as regulatory pressure, systems interoperability, and standards maturity shape the suitability of information-sharing technologies. The expert interview further confirmed that the framework's structure and terminology were understandable and actionable, while also providing suggestions for improving clarity and grouping of contextual factors.

While these results offer initial evidence of the potential practical relevance of the framework, they remain exploratory in scope. The analysis is limited to two pilot-driven projects and one expert perspective, which means that the findings are interpreted as a first step rather than a definitive validation. Nevertheless, the consistency between the framework's suggestion and the information-sharing approach in the cases suggests that the framework can serve as a useful starting point for SMEs considering digital solutions under various weighted contextual factors.

7 Conclusion

This research aimed to address a critical and timely question at the intersection of sustainability, digital transformation, and small business innovation, the main research question being ”Which conceptual framework shows the relationship between context-based factors and information-sharing systems for circular business activities by SMEs?” Motivated by growing policy emphasis on circularity exemplified by initiatives like the digital product passport, this thesis developed a conceptual framework that links information-sharing archetypes to SME specific contextual factors.

To systematically address this overarching research question, the study was decomposed into four interrelated sub-research questions. Each sub-question explored a distinct phase of the methodology, which collectively formed a structured, design science-based investigation into the interplay between information-sharing archetypes and context-awareness factors for SMEs in the circular economy domain. The first sub-question examined the current landscapes of digital technologies adopted in CE transitions through a structured literature review. The second identified key contextual factors, such as system interoperability, regulatory pressure, and firm size, influence SME adoption of these technologies.

The third sub-research question integrated these insights by mapping contextual factors identified and the information-sharing archetypes. The LMH (Low-Medium-High) ratings summarized in 5.1 were determined by evaluating how each contextual factor influences the suitability of different information-sharing archetypes, based on sector-specific literature and SME constraints. Each rating reflects both the technical requirements of a solution and the organizational readiness needed for its adoption. For example, Blockchain-based solutions (BCL) are rated ”High” for data governance and systems interoperability due to their robust traceability capabilities, but ”Low” for usability in SMEs with limited digital maturity or workforce data skills, as their technical complexity can create barriers. In contrast, cloud platforms (BCP) are rated ”High” on systems interoperability and usability because of their flexibility and ease of integration, but ”Medium” on financial slack, as recurring subscription costs can still pose challenges for resource-constrained SMEs. This mapping approach ensures that the ratings in Table 5.1 capture practical trade-offs SMEs face when selecting information-sharing solutions under various contextual conditions.

The fourth sub-research question concerned the validation of the proposed framework. Due to constraints in access and time, this was conducted through two modes: semi-structured interviews with one SME stakeholder, and validation through walkthrough applications of EU-funded projects found in the CIRPASS initiatives that were in the application phase. These case-informed validations reinforced the internal consistency and practical plausibility of the framework. Although the sample size was limited, the interviews provided rich, qualitative feedback on the relevance of the contextual factors and the perceived alignment of technology options. The theoretical walkthroughs, grounded in real project documentation, demonstrated how the framework could be applied to trace the logic of decision-making in real-world CE technology implementation.

From this comprehensive research process, several valuable insights emerged. First, context truly matters—SMEs are not a homogeneous group, and their capacity to adopt digital tools is profoundly shaped by their internal and external environments. Second, the current digital landscape for CE is fragmented, with significant variation across sectors and countries in terms of tool maturity, standardization, and interoperability. Third, policy instruments like the DPP, while visionary, must be accompanied by practical guidance and infrastructure that support SMEs in making informed and realistic digital choices.

The societal and scientific contributions of this thesis are multifaceted. Societally, the framework developed here offers policymakers, industry consortia, and SME support platforms a practical tool to guide digital transformation in ways that are sensitive to the unique constraints and capabilities of small firms. It aligns with growing EU efforts to democratize access to digital infrastructure and promote sustainable business models. Scientifically, this study contributes to the literature by addressing the lack of integrated approaches that combine contextual factors with information-sharing archetypes for SMEs in circular economy transitions. As identified in the structured literature review (e.g., (Battistoni et al., 2023; Thirumal et al., 2024; Tsvetkova et al., 2020; Winter et al., 2023), most studies focused either on digitalisation or CE goals in isolation, often lacking a practical decision-support framework. This thesis tries to bridge that gap by applying DSR to develop a conceptual framework that could guide SMEs based on their operational realities. Additionally, based on interview feedback, the clustering of contextual factors into broader domains - such as product, market, and finance - may support more structured interdisciplinary dialogue between innovation management, information systems, and circular governance.

That said, this study is not without limitations. While the conceptual framework was developed through a structured process, several methodological and scope-related constraints should be acknowledged. The LMH ratings presented in 5.1 were derived from literature and conceptual interpretation and have not been validated with practitioners and SME, and no formal criteria were defined to guide SMEs in assigning Low, Medium, or High scores. Additionally, the absence of ”Low” ratings for Firm size in table 5.1 reflects a literature-driven gap that limits the framework's applicability to very small or early-stage firms. Furthermore, only one interview could be conducted within the available time frame, which limits the ability to assess the framework's broader applicability. In terms of scope, the analysis focused on six sectors selected for relevance to EU circular economy policy. While these sectors are representative, others such as - Healthcare, education, or logistics - may exhibit different contextual conditions. The number of digital systems combinations considered, though substantial, does not cover the full breadth of an evolving digital ecosystem. Future work could expand the framework to incorporate technologies like AI, digital twins, and test it more broadly through longitudinal and multi-sector studies. Finally, based on feedback from the validation interview, future iterations may explore clustering the eleven contextual factors into broader themes - such as product, market, legal, team, and financial - which could improve readability and usability across different SME contexts.

To implement the proposed framework in practice, it is recommended that SME support agencies and industry associations adapt the tool into an interactive decision support system. This could be deployed in digital readiness assessments, innovation vouchers, or CE acceleration programs. Customizing the tool for sector-specific conditions and embedding it within existing platforms such as Enterprise Europe Network or DIH portals would greatly enhance accessibility and uptake.

From an educational standpoint, this thesis reflects the interdisciplinary aspect of the Management of Technology (MoT) program at TU Delft. The project required integrating innovation management, policy design, and systems thinking. Applying DSR allowed the translation of theoretical insights into a structured artefact, while also embracing iteration and feedback - key elements of MoT thinking. This thesis showcases the MoT ambition to bridge analytical rigor with practical, problem-driven relevance.

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A

Sub RQ1 Codebook

A.1. Appendix A.1

Table A.1: Complete List of Open Codes with Key Citations

No.	Code	APA Citation
1	19 critical barriers via Pareto analysis	(Thirumal et al., 2024)
2	22 barriers grouped into infrastructure/economic, technology, governance categories	(Liu et al., 2021)
3	37 barriers ’ 9 categories	(Thirumal et al., 2024)
4	3-level ROI assessment shows benefits of transformable buildings	(“Circular Construction In Regenerative Cities (CIRCuIT)”, 2025)
5	48 SME-led solutions funded; ,¬100k grants + investor matchmaking	(DigiCirc Consortium, 2024)
6	6Rs strategy (reduce, reuse, recycle, reclaim, recover, restore) guides CE transition	(Mbavarira & Grimm, 2021)
7	AAS sub-model templates for CE	(Kühn et al., 2025)
8	AI model flags supply-chain flow anomalies to support due-diligence	(B2FRESH Consortium, 2018)
9	battery value-chain digital platform	(Orko & Lavikka, 2023)
10	BIM-based material passport	(Iva Kovacic et al., 2024)
11	Blockchain + Big Data framework enhances textile supply-chain traceability	(Hader et al., 2022)
12	Blockchain addresses asymmetric information & trust issues	(Hader et al., 2022)
13	Blockchain consortium (Aura) combats counterfeiting in luxury fashion	(Chen, 2024)
14	Blockchain interoperability enables cradle-to-cradle textile traceability	(“European Union 2024”, 2025)
15	Blockchain supports labor-condition transparency in India’s fashion sector	(Chen, 2024)
16	Casino archetype business model (coop-etition)	(García-Álvarez De Perea et al., 2019)
17	Circular construction hub develops indicators: Urban Mining Index, Lifespan Index	(“Circular Construction In Regenerative Cities (CIRCuIT)”, 2025)
18	Circular model promises new revenue streams for water utilities	(Mbavarira & Grimm, 2021)
19	closed-loop hydroponic model	(Farace & Tarabella, 2024)
20	collaboration & info-sharing CSFs	(Thirumal et al., 2024)
21	collaborative innovation under competition	(García-Álvarez De Perea et al., 2019)

No.	Code	APA Citation
22	collaborative value creation via platforms	(Orko & Lavikka, 2023)
23	Consumer demand for transparency drives digitalisation	(Heim & Hodson, 2023)
24	Created 4 digital tools: matchmaking, CE data hub, industrial symbiosis, info portal	("Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks (DigiPrime)", 2025)
25	cross-sector federated services for SMEs	(Pedone et al., 2021)
26	Current systems suffer poor traceability & real-time info-sharing delays	(Hader et al., 2022)
27	data gaps as CE bottlenecks	(Orko & Lavikka, 2023)
28	data-related & standardisation hurdles	(Thirumal et al., 2024)
29	Decision-Analytics Platform aids policy makers in robust water planning	(IRIS SRL, 2024)
30	Demonstrator garments recycled up to 80% mechanically-reclaimed cotton	(SCIRT Consortium, 2024).
31	Developed 23 eco-solutions to cut food loss & waste across value chain	(FOODRUS Consortium, 2025)
32	Digital tech (IoT, blockchain, AI) key enablers for circular textile business models	(FOODRUS Consortium, 2025)
33	Digital tech know-how & CE awareness ranked among most critical barriers	(Liu et al., 2021)
34	digital triggers resource optimisation	(Farace & Tarabella, 2024)
35	Digitalisation, water reuse & resource recovery underpin circularity in utilities	(Mbavarira & Grimm, 2021)
36	Distributed small-loop water reuse demonstrated via modular pilot plants	(IRIS SRL, 2024)
37	DPP adoption factors: enablers & hindrances	(Berger et al., 2023)
38	early design freeze critical	(Thirumal et al., 2024)
39	Eco-modulated EPR model designed for apparel transparency incentives	VITO. (2023). Periodic Reporting period1 - SCIRT - cordis 453726 .
40	Eight European case studies reveal barriers & enablers of product-service systems	Antikainen, R. etal. (2021). Circular business models: Product-service systems on the way to a circular economy. EPA Network.
41	ELV material scarcity awareness	(Rosa & Terzi, 2023)
42	Federated semantic data platform unlocks cross-sector circular value chains	Politecnico di Milano. (2024). Periodic Reporting period3 - DigiPrime cordis 873111.
43	Fibersort + Trimclean tech improve textile-to-textile recycling quality	European Commission. (2025). Recycling textiles: from collection to retail.
44	four-layer tech stack: Sensor ' Integration ' Intelligence ' Response	(Pedone et al., 2021)
45	fuzzy-Delphi / WINGS causal map methodology	(Sonar et al., 2024)
46	integrated CE information platform	(Yu et al., 2022)
47	Guidelines help practitioners match CI method families to FSC problem types	(Angarita-Zapata et al., 2021)
48	high investment cost of digital transformation	(Ozbiltekin-Pala & Aracıoglu, 2024)
49	Identifies cost elements & benefits of Digital Product Passport for SMEs	(Bernier et al., 2024)
50	Inadequate water-supply infrastructure constrains SME operations	(Bessy Eva Kathambi et al., 2021)
51	information asymmetry in automotive recycling	(Rosa & Terzi, 2023)
52	information quality as mediator	(Namagembe & Mbago, 2023)

No.	Code	APA Citation
53	information sharing not always significant	(Ma et al., 2022)
54	Integrated blockchain platform offers secure data sharing & scalability	(Chen, 2024)
55	inter- / intra-firm data platform (DEEP)	(Iva Kovacic et al., 2024)
56	Interest in decentralised wastewater-treatment solutions for circularity	(Liu et al., 2021)
57	interoperability & data sovereignty requirements	(Kühn et al., 2025)
58	Investment & legal-framework gaps slow CE uptake	(Mbavarira & Grimm, 2021)
59	lack of BoL-EoL data exchange	(Rosa & Terzi, 2023)
60	lack of info & post-harvest mishandling	(Sonar et al., 2024)
61	lack of IT infrastructure	(Ozbiltekin-Pala & Aracıoglu, 2024)
62	legal problems & missing policies	(Ozbiltekin-Pala & Aracıoglu, 2024)
63	lower layers enable upper layers (dependency)	(Pedone et al., 2021)
64	managerial competencies ’ info sharing ’ SC performance	(Namagembe & Mbago, 2023)
65	Marketplace offers 6 micro-services: PEF, circular assessment, AI anti-counterfeiting	(“European Union 2024”, 2025)
66	MCS used diagnostically	(García-Álvarez De Perea et al., 2019)
67	Multi-level governance gaps hinder sustainable water use by SMEs	(Bessy Eva Kathambi et al., 2021)
68	NFT innovation (Nike) merges digital & physical product experiences	(Chen, 2024)
69	OECD water-governance principles used as diagnostic for policy gaps	(Bessy Eva Kathambi et al., 2021)
70	One-stop digital platform offers predictive insights for F&V supply-chain	(B2FRESH Consortium, 2018)
71	Open calls recruit IT developers to extend circular services marketplace	Politecnico di Milano. (2024). Periodic Reporting period3 - DigiPrime.
72	operational services as a service (DOS)	(Pedone et al., 2021)
73	Over-institutionalisation & overlapping roles create regulatory confusion	(Bessy Eva Kathambi et al., 2021)
74	Pan-European accelerator links clusters & SMEs for digital circular innovations	(DigiCirc Consortium, 2024)
75	PAYT ordinance with blockchain incentivises household waste prevention	(FOODRUS Consortium, 2025)
76	pharma supply disruptions (COVID-19)	(Ma et al., 2022)
77	Proposed CI-based taxonomy for food supply-chain problems (production-retail)	(Angarita-Zapata et al., 2021)
78	Proposes three-phase deployment scenario for textile digital product passport	(European Parliament. Directorate General for Parliamentary Research Services., 2024)
79	Scalability identified as primary technical challenge for blockchain	(Hader et al., 2022)
80	seven ICT branches relevant to CE	(Yu et al., 2022)
81	slowing loop vs. closing loop data needs	(Kühn et al., 2025)
82	smart circular ecosystem concept	(Yu et al., 2022)
83	Smart tags & forensic tracers cited as traceability tools	(Heim & Hodson, 2023)
84	Smart water systems often fail to promote circularity goals in practice	(Liu et al., 2021)
85	SME access to CE markets	(Pedone et al., 2021)
86	SME data readiness gap	(Khan & Abonyi, 2022)
87	SME resource constraints hinder adoption	(Pedone et al., 2021)

No.	Code	APA Citation
88	SMEs experience software overload & integration complexity	(Heim & Hodson, 2023)
89	specialist contractor leadership	(Thirumal et al., 2024)
90	stakeholder classification (innovators laggards)	(Berger et al., 2023)
91	sustainability & resilience linkage	(Farace & Tarabella, 2024)
92	system-level view of material and value cycles	(Orko & Lavikka, 2023)
93	TOE + DOI framework for technology uptake	(Berger et al., 2023)
94	traceability acts as mediator	(Ozbiltekin-Pala & Aracıoglu, 2024)
95	traceability plays mediating role	(Ma et al., 2022)
96	True Cost Calculator gives stakeholders holistic garment cost incl. social impact	(European Union, 2025a)
97	trust & standardisation barriers	(Khan & Abonyi, 2022)
98	upstream vs. downstream data flow imbalance	(Khan & Abonyi, 2022)
99	urban mining cadastre concept	(Iva Kovacic et al., 2024)
100	Web3 adoption guide proposed for fashion SMEs	(Heim & Hodson, 2023)
101	A package of ICT tools for FLW monitoring and decision-making in food systems	(FOODRUS Consortium, 2025)
102	Blockchain-enabled Pay As You Throw model for waste reduction incentives	(FOODRUS Consortium, 2025)
103	A data platform to support digital circular economy transitions	(DigiCirc Consortium, 2024)
104	A collaborative platform for circular resource exchange among firms	(DigiCirc Consortium, 2024)
105	High-speed robotic textile sorting using NIR technology	(European Union, 2024c)
106	Robotic textile dismantling technology that segments and scans textile fragments	(European Union, 2024c)
107	Tool for assessing the societal cost of garments	(European Union, 2024c)
108	Multi-sectoral water circularity assessment methodology	(European Union, 2024a)
109	Solar-powered desalination system integrated in water loops	(European Union, 2024a)
110	Nature-based water treatment loop combining CWs, anaerobic digestion, and UV	(European Union, 2024a)
111	User-centered collaborative platform for circularity in water reuse	(European Union, 2024b)
112	ICT platform for water planning and portfolio assessment	(European Union, 2024b)
113	Small-scale, solar-supported water treatment systems	(European Union, 2024b)
114	Tool designed to identify potential industrial symbiosis loops	(“Circular Construction In Regenerative Cities (CIRCuIT)”, 2025)
115	Decision support tool to model scenarios and design circular interventions in food supply chains	(“European Union 2024”, 2025)
116	Digital platform enabling collaboration between farmers, retailers, and municipalities	(“European Union 2024”, 2025)
117	Sensors installed in waste bins track fill levels and contamination rates	(“European Union 2024”, 2025)
118	Nutrient monitoring system developed for circular agriculture integration	(“European Union 2024”, 2025)
119	Visual tools supporting SMEs to navigate regulatory and business decisions in CE transitions	(“Circular Construction In Regenerative Cities (CIRCuIT)”, 2025)
120	Tool that guides designers in incorporating CE principles into textile and fashion design decisions	(“Circular Construction In Regenerative Cities (CIRCuIT)”, 2025)

No.	Code	APA Citation
121	E-labeling tool allowing traceable and updatable sustainability labels for garments	(European Union, 2025a)
122	Diagnostic tool assessing readiness of urban areas to implement CE projects	(European Union, 2024c)
123	Decision-support system to evaluate industrial-urban symbiosis opportunities	(European Union, 2024c)
124	Planning module for identifying risks in CE water project implementation	(European Union, 2024c)
125	Toolkit supports continuous monitoring and reporting for CE-related urban planning	(European Union, 2024c)
126	Platform that maps CE-related actors and suggests partnership options	("Circular Construction In Regenerative Cities (CIRCuIT)", 2025)
127	Linked data infrastructure for product material properties and circularity indicators	("Circular Construction In Regenerative Cities (CIRCuIT)", 2025)
128	Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks	("Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks (DigiPrime)", 2025)
129	Digital tools customized for different user needs at different CE maturity levels	("Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks (DigiPrime)", 2025)
130	Machine learning model for identifying anomalies in supply chain flows	(European Union, 2022)
131	User-driven correction mechanism in supply chain risk analysis	(European Union, 2022)
132	Interoperable DPP data model for SME-scale circular transparency	(Bernier et al., 2024)
133	Digital product passport tailored for the textile sector, integrating lifecycle and material data	(European Parliament. Directorate General for Parliamentary Research Services., 2024)
134	Supports product journey visibility, lifecycle emissions, and durability data sharing	(European Parliament. Directorate General for Parliamentary Research Services., 2024)
135	Combines IoT, AI, CAD, and VR/AR for circular textile design and transparency	(Manshoven et al., 2025)
136	Simulates CE impact scenarios for fashion and textiles firms	(Manshoven et al., 2025)
137	AI-driven yield optimization for reducing farm input waste	(Howard et al., 2022)
138	Digital twin platform for real-time construction waste monitoring	(Yu et al., 2022)
139	Circular manufacturing platform integrating RFID and cloud data flows	(Battistoni et al., 2023)
140	QR-based traceability interface for eco-labels and consumer transparency	(Hader et al., 2022)
141	Process analytical technology	(Ma et al., 2022)
142	platform architecture	(Namagembe & Mbago, 2023)
143	stakeholder coordination	(Namagembe & Mbago, 2023)
144	data-driven resilience	(Namagembe & Mbago, 2023)
145	sustainability barrier mapping	(Sonar et al., 2024)
146	strategic decision aid	(Sonar et al., 2024)
147	post-harvest traceability	(Sonar et al., 2024)
148	market-responsive design	(García-Álvarez De Perea et al., 2019)
149	consumer-driven tool configuration	(García-Álvarez De Perea et al., 2019)
150	Battery value-chain digital platform	(Berger et al., 2023)

No.	Code	APA Citation
151	Sustainability performance enablement	(Berger et al., 2023)
152	DPP adoption framework	(Berger et al., 2023)
153	Inter-organizational integration	(Ozbiltekin-Pala & Aracıoglu, 2024)
154	Real-time coordination infrastructure	(Ozbiltekin-Pala & Aracıoglu, 2024)
155	Digital readiness assessment	(Orko & Lavikka, 2023)
156	Interoperable standardization	(Orko & Lavikka, 2023)
157	Secure communication framework	(Orko & Lavikka, 2023)
158	Waste stream digitalization	(Ma et al., 2022)
159	Predictive circular intelligence	(Ma et al., 2022)
160	Machine learning for resource recovery	(Ma et al., 2022)
161	Lifecycle transparency tools	(Kühn et al., 2025)
162	Compliance-oriented data hubs	(Kühn et al., 2025)
163	Modular data passports	(Kühn et al., 2025)
164	BIM-Digital Twin integration	(Yu et al., 2022)
165	Disassembly lifecycle mapping	(Yu et al., 2022)
166	Traceability-enhanced modeling	(Yu et al., 2022)
167	Fraud prevention via blockchain	(Wuni & Shen, 2022)
168	Trust enhancement protocols	(Wuni & Shen, 2022)
169	Material salvage traceability	(Wuni & Shen, 2022)
170	Construction digital passport	(Iva Kovacic et al., 2024)
171	Environmental performance ledger	(Iva Kovacic et al., 2024)
172	Compositional transparency hub	(Iva Kovacic et al., 2024)
173	SME adoption constraints	(Thirumal et al., 2024)
174	Digital literacy enabler	(Thirumal et al., 2024)
175	Value proposition articulation	(Thirumal et al., 2024)
176	Garment supply chain traceability	(Hader et al., 2022)
177	Fiber authentication system	(Hader et al., 2022)
178	Digital labeling mechanism	(Heim & Hodson, 2023)
179	Eco-label standardization	(Heim & Hodson, 2023)
180	Circular design integration	(Rinaldi et al., 2022)
181	Lifecycle impact visualization	(Rinaldi et al., 2022)
182	AI-driven sortation	(Chen, 2024)(Chen, 2024)
183	Post-consumer textile recovery	(Chen, 2024)
184	Blockchain for transparency	(Kazancoglu et al., 2022)
185	Stakeholder trust framework	(Kazancoglu et al., 2022)
186	multi-tier information integration	(Winter et al., 2023)
187	MSCM data disparity reduction	(Winter et al., 2023)
188	supplier network transparency	(Winter et al., 2023)
189	cross-sectorial data service platform	(Pedone et al., 2021)
190	operational services as a service	(Pedone et al., 2021)
191	reverse logistics coordination	(Pedone et al., 2021)
192	decentralized information control	(Battistoni et al., 2023)
193	agent-based data coordination	(Battistoni et al., 2023)
194	integrated product lifecycle platform	(Rosa & Terzi, 2023)
195	closed-loop information architecture	(Rosa & Terzi, 2023)
196	predictive environmental monitoring	(Arranz et al., 2024)
197	real-time data visibility	(Arranz et al., 2024)
198	blockchain-enabled trust	(Liu et al., 2021)
199	quality verification traceability	(Liu et al., 2021)
200	secure environmental reporting	(Liu et al., 2021)
201	infrastructure maintenance planning	(Cahn et al., 2023)
202	wastewater process integration	C(Cahn et al., 2023)
203	IoT-based leakage detection	(Cahn et al., 2023)
204	policy compliance facilitation	(Mbavarira & Grimm, 2021)

No.	Code	APA Citation
205	mobile water reporting tools	(Mbavarira & Grimm, 2021)
206	community-centric information systems	(Mbavarira & Grimm, 2021)
207	regional dashboard integration	(Bessy Eva Kathambi et al., 2021)
208	multi-source data harmonization	(Bessy Eva Kathambi et al., 2021)

A.2. Appendix A.2

Figure A.1: Codes clustered to Archetypes of technologies

Archetypes	Code Frequency	Example Codes
BCL	27	Blockchain + Big Data framework enhances textile supply-chain traceability Blockchain interoperability enables cradle-to-cradle textile traceability Blockchain for transparency
BCP	30	A collaborative platform for circular resource exchange among firms platform architecture cross-sectorial data service platform
DIH	80	lack of IT infrastructure Waste stream digitalization integrated CE information platform
DPP	18	DPP adoption framework Identifies cost elements & benefits of Digital Product Passport for SMEs Construction digital passport
IoT	25	IoT sensor gateways IoT-based leakage detection Combines IoT, AI, CAD, and VR/AR for circular textile design and transparency
SEM	28	Decision-support system to evaluate industrial-urban symbiosis opportunities Machine learning model for identifying anomalies in supply chain flows digital triggers resource optimisation

B

sub RQ2 codebook

B.1. Appendix B.1

Table B.1: Complete List of Open Codes with Key Citations

No.	Code	APA Citation
1	A holistic framework for continuous data and information flows is lacking	(Iva Kovacic et al., 2024)
2	Adoption of different digital technologies enables data-driven decision-making	(Battistoni et al., 2023)
3	alliances reduce innovation barriers	(García-Álvarez De Perea et al., 2019)
4	barriers related to recycling technologies, digital technology know-how, and the lack of CE awareness	(Liu et al., 2021)
5	blockchain improves pharmaceutical safety	(Ma et al., 2022)(Ma et al., 2022)
6	businesses reluctant to share sensitive data	(Orko & Lavikka, 2023)(Orko & Lavikka, 2023)
7	challenges in cross-border logistics	(Majumdar et al., 2021)(Majumdar et al., 2021).
8	Circular-economy drivers can be grouped into five clusters: products, processes, policies/regulations, attitudes/behaviors, and communication/awareness	(Oliveira et al., 2024)
9	collaboration enables resource pooling	(García-Álvarez De Perea et al., 2019)
10	competition fosters collaborative innovation	(García-Álvarez De Perea et al., 2019)
11	Construction sector faces new obstacles due to increasing complexity and stakeholder diversity	(Thirumal et al., 2024)
12	Current management tools such as value mapping, life cycle assessment, modeling & simulation, and capability maturity can assist SMEs towards becoming more circular and sustainable	(Howard et al., 2022)
13	customer responsiveness as key to adaptation	(Sonar et al., 2024)
14	Data about materials embedded in cars are inaccessible due to protected databases	(Rosa & Terzi, 2023)
15	data gaps hinder circular design	(Orko & Lavikka, 2023)
16	data quality and lack of talent are major barriers to big data adoption	(Cahn et al., 2023)
17	dependence on intermediaries	(Majumdar et al., 2021).
18	difficulty aligning quality standards internationally	(Farace & Tarabella, 2024)

No.	Code	APA Citation
19	Digital innovation has a close connection with firms' sustainability. Sustainability and digital innovation are two essential components of the circular economy	(Yang et al., 2023)
20	digital literacy has been proven to significantly and positively impact digital business transformation	(Raharjo et al., 2024)
21	digital passports fill lifecycle data gaps	(Berger et al., 2023)
22	digital readiness characterized by technological sensemaking, agility, and implementation	(Pingali et al., 2023)
23	Digital technologies have significant potential to support CE in Architecture, Engineering and Construction (AEC)	(Iva Kovacic et al., 2024)
24	digital traceability boosts resilience	(Ma et al., 2022)
25	Digitalization is mainly enabled by Sensor technologies	(Battistoni et al., 2023)
26	digitalization, water reuse and resource recovery underpin circularity	(Mbavarira & Grimm, 2021)
27	experts are interested in decentralized wastewater treatment system	(Liu et al., 2021)
28	export experience accelerates decision-making	(Farace & Tarabella, 2024)
29	exporting drives innovation	(Farace & Tarabella, 2024)
30	external (i.e., suppliers and customers) and internal (i.e., employees, organizational culture, and competitive advantage) factors... linked to sustainability practices	(Tsvetkova et al., 2020)
31	family-owned structure affects internationalization	(Farace & Tarabella, 2024)
32	financial constraints in DT implementation	(Ozbiltekin-Pala & Aracıoglu, 2024)
33	financial literacy positively affects SME financial accessibility and financial risk	(Kurniasari et al., 2023)
34	financial risk perception in global expansion	(Sonar et al., 2024)
35	Forty-seven (47) influencing factors are identified and classified into four groups based on the TOEI framework	(Naushad & M. M, 2020)
36	gap between intention and effective action	(Arranz et al., 2024)
37	Globalization and digitalization force SMEs to redefine competitive strategies continuously.	(Thrassou et al., 2020)
38	High innovation potential linking car parts suppliers and carmakers with End-of-Life actors	(Rosa & Terzi, 2023)
39	Identified thirty-seven barriers to using DTs to implement CE, categorized into nine areas	(Thirumal et al., 2024)
40	importance of local partnerships	(Majumdar et al., 2021).
41	information sharing catalyzes transparency	(Ma et al., 2022)
42	information silos among stakeholders	(Orko & Lavikka, 2023)
43	infrastructure limitations	(Ozbiltekin-Pala & Aracıoglu, 2024)
44	initial feasibility barriers primarily perceived by senior managers	(Arranz et al., 2024)
45	Integration of eco-repository data and public policy regulations into a digital platform is necessary	(Iva Kovacic et al., 2024)
46	investment and lack of enabling legal framework slow CE uptake	Mbavarira & Grimm (2021)
47	knowledge of foreign consumer behavior	(Majumdar et al., 2021).
48	lack of collecting, sorting and recycling	(Kazancoglu et al., 2022)

No.	Code	APA Citation
49	lack of financial capacity, low market demands, restrictions with regard to capital, and barriers in the supply chain	(Zhang & Wang, 2022)
50	lack of platform interoperability	(Orko & Lavikka, 2023)
51	lack of scalability in small firms	(Farace & Tarabella, 2024)
52	Lack of technical know-how and perceived affordability influence SME managers' behaviour towards ICT adoption.	(Eze et al., 2018)
53	lack of technical knowledge is the most influencing factor	(Kazancoglu et al., 2022)
54	language and cultural barriers	(Sonar et al., 2024)
55	limited access to foreign market information	(Majumdar et al., 2021).
56	longevity of the business was identified as an additional sustainability maintenance factor	(Tsvetkova et al., 2020)
57	market entry barriers for SMEs	(Majumdar et al., 2021).
58	maturity of digital technologies and knowledge strategies influence small business performance	(Ferreira et al., 2024)
59	misconceptions about DT reliability	(Ozbiltekin-Pala & Aracıoglu, 2024)
60	MNEs and SMEs share internationalization archetypes	(García-Álvarez De Perea et al., 2019)
61	need for more attention from SMEs and policymakers responding to the twin transformation objectives	(Burinskienė & Nalivaikė, 2024)
62	networks are alternative to firm growth	(García-Álvarez De Perea et al., 2019)
63	Operational services help SMEs overcome information asymmetry	(Pedone et al., 2021)
64	Ownership structure and limited resources are the most influential contextual factors in ERP implementation.	(Zach et al., 2014)
65	perceived complexity slows DPP adoption	(Berger et al., 2023)
66	Profitability and top management support are other prime factors that stimulate ICT adoption.	(Naushad & M. M, 2020)
67	public vs private sector alignment gaps	(Ozbiltekin-Pala & Aracıoglu, 2024)
68	regulatory barriers to digital tech adoption	(Ozbiltekin-Pala & Aracıoglu, 2024)
69	regulatory complexity limits market scope	(Sonar et al., 2024)
70	reluctance for acceptance of CE model	(Kazancoglu et al., 2022)
71	resource-related barriers during implementation	(Arranz et al., 2024)
72	risk aversion and siloed operations hamper innovation	(Cahn et al., 2023)
73	risk management via digital systems	(Ma et al., 2022)
74	SMEs are more vulnerable to economic crises and exogenous shocks compared to large firms.	(Miklian & Hoelscher, 2022)
75	SMEs face barriers in MSCM due to missing trust and standardization	(Winter et al., 2023)
76	SMEs face serious challenges from digitization and technology adoption in volatile business environments.	(Naushad & M. M, 2020)
77	SMEs leverage digital tools for market analysis	(Farace & Tarabella, 2024)
78	SMEs must develop contextual dynamic capabilities to survive in an era of continuous change.	(Thrassou et al., 2020)

No.	Code	APA Citation
79	SMEs must plan and analyze technology across their business model and processes, and employ innovation as a strategy to close the technical gap and maintain competitiveness	(Gupta et al., 2022)
80	SMEs should devote attention to non-technical aspects of BDACs as well. Specifically, they require more outsourcing and external collaborations	(Moonen et al., 2019)
81	SMEs show varied resilience strategies, ranging from innovation to diversification, shaped by the context of the crisis.	(Miklian & Hoelscher, 2022)
82	SMEs significantly lag behind large organizations in benefiting from disruptive Industry 4.0 technologies	(Ghobakhloo et al., 2022)
83	stakeholder buy-in is crucial	(Berger et al., 2023)
84	supply chain reliability impacts reputation	(Sonar et al., 2024)
85	Switching from a linear to a circular flow will require significant stakeholder collaboration	(Thirumal et al., 2024)
86	system view required for circularity	(Orko & Lavikka, 2023)
87	The AEC industry tries to apply new technologies within the conventional processes, thereby lacking complete achievement of expected benefits	(Iva Kovacic et al., 2024)
88	The framework was structured to help industries implement responsible digitalization initiatives in five key stages... validating the proposal in the context of an SME allowed us to discern the tangible benefits of sustainability practices	(Martínez-Peláez et al., 2024)
89	The implementation phase of ERP systems is most sensitive to the SME context due to limited expertise and resources.	(Zach et al., 2014)
90	the limited and fragmented application of today's digital and sustainable technologies in SMEs	(Burinskienė & Nalivaikė, 2024)
91	The main finding of this research is the key role of information as a facilitator for the adoption of CE strategies in manufacturing	(Acerbi & Taisch, 2020)
92	The proposed model is based on a set of 11 selection criteria and 94 metrics, which were generated based on the characteristics of software-developing SMEs	(Rivas et al., 2008)
93	trust in international alliances	(Majumdar et al., 2021).
94	Uncertainty, market dynamics, and lack of resources are key drivers influencing information behavior in ICT adoption.	(Eze et al., 2018)
95	uneven tech adoption across supply chains	(Ma et al., 2022)
96	unseen players determine outcomes in water sector	(Bessy Eva Kathambi et al., 2021)
97	We designed the system based on use cases and user typology... to guide practitioners through the tool jungle with the potential to grow into a lively community	(Quade et al., 2012)
98	weak regulatory arrangements and overlapping roles challenge water governance	(Bessy Eva Kathambi et al., 2021)
99	Low tech absorption capacity	(Yang et al., 2023)
100	Green legitimacy pressure	(Tsvetkova et al., 2020)
101	Eco-certification alignment	(Tsvetkova et al., 2020)
102	Centralized data visibility	(Zach et al., 2014)
103	Contextual inefficiencies in resource monitoring	(Cahn et al., 2023)

No.	Code	APA Citation
104	Intra-firm change agents	(Oliveira et al., 2024)
105	Institutional training dependency	(Oliveira et al., 2024)
106	Fragmented digital capacity	(Thrassou et al., 2020)
107	Misaligned digital tools	(North et al., 2019)
108	low digital maturity	(Pingali et al., 2023)
109	compliance overload	(Pingali et al., 2023)
110	regulatory uncertainty	(Pingali et al., 2023)
111	certification-driven data demands	(Tsvetkova et al., 2020)
112	supply chain fragmentation	(Wuni & Shen, 2022)
113	information asymmetry	(Oliveira et al., 2024)
114	tiered trust levels	(Wuni & Shen, 2022)
115	communication lags	(Pedone et al., 2021)
116	institutional facilitation gap	(Omrani et al., 2024a)
117	government program dependency	(Omrani et al., 2024a)
118	public-private partnership leverage	(Omrani et al., 2024a)
119	Trust deficit	(Arranz et al., 2024)
120	Ecosystem participation	(Bernier et al., 2024)
121	Regulatory incentive alignment	(“Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks (DigiPrime)”, 2025)
122	Customer interoperability pressure	(Ma et al., 2022)
123	Organizational inertia	(Battistoni et al., 2023)
124	Data governance maturity	(Seidel et al., 2009)

B.2. Appendix B.2

Figure B.1: Axial Coding

Row Labels	Count of Open Code	Sample code
Data Culture	8	data gaps hinder circular design language and cultural barriers
Digital Agility	5	Globalization and digitalization force SMEs to redefine competitive strategies continuously SMEs face serious challenges from digitization and technology adoption in volatile business environments
Digital Maturity Tier	8	Adoption of different digital technologies enables data-driven decision-making Low tech absorption capacity
Ecosystem Support	10	dependence on intermediaries government program dependency
Financial Slack	4	financial constraints in DT implementation financial risk perception in global expansion
Firm Size	8	lack of scalability in small firms family-owned structure affects internationalization
IT Infrastructure Maturity	3	infrastructure limitations
Leadership Openness	3	Organizational inertia
Managerial Bandwidth	5	gap between intention and effective action
Market & Consumer Pull	6	knowledge of foreign consumer behavior
Network Embeddedness	8	alliances reduce innovation barriers
Regulatory Pressure	7	regulatory complexity limits market scope
Resource Capacity	7	lack of scalability in small firms
Standards Maturity	2	certification-driven data demands
Supply-Chain Dynamics	5	SMEs face barriers in MSCM due to missing trust and standardization
Sustainability Orientation	10	Circular-economy drivers can be grouped into five clusters: products, processes, policies/regulations, attitudes/behaviors, and communication/awareness
System Interoperability	9	lack of platform interoperability
Tool-Task Fit	11	Misaligned digital tools
Training and Knowledge Sharing	2	Intra-firm change agents
Workforce Data Skills	3	lack of technical knowledge is the most influencing factor

C

SubRQ3 codebook

C.1. Appendix C.1

Figure C.1: Codebook

Sector	Firm Size	Digital Maturity Tier	System Interoperability	Financial Slack	Leadership Openness	Workforce Data Skills	Network Embeddedness	Regulatory Pressure	Market & Consumer Pull	Standards Maturity	Ecosystem Support
Agrifood		• (Pingali 2023; Raharjo 2024)					• (Oliveira 2024; Sonar 2024)		• (Sonar 2024; Tsvetkova 2020)		
Construction			• (Orko & Lavikka 2023; Zach 2014)					• (Thirumal 2024; Ozbiltekin-Pala & Aracıoglu 2024)		• (Sabatini 2023; "Drivers…" 2022)	
Chemical			• (Orko & Lavikka 2023; Fukushige 2023)	• (Kurniasari 2023; Ozbiltekin-Pala & Aracıoglu 2024)				• (Ozbiltekin-Pala & Aracıoglu 2024; Berger 2023)			
Manufacturing		• (Battistoni 2023; Pingali 2023)	• (Noël 2023; Zach 2014)	• (Kurniasari 2023; Ozbiltekin-Pala & Aracıoglu 2024)							
Textile									• (Chen 2024; Rinaldi 2022)	• (Sabatini 2023; Lopes 2024)	• (Binek & Small 2020; Gatto 2022)
Water		• (Mbavarira & Grimm 2021; Battistoni 2023)	• (Kathambi 2021; Cahn 2023)					• (Kathambi 2021; Mbavarira & Grimm 2021)			• (Mbavarira & Grimm 2021; Kathambi 2021)

Contextual Factor	BCL + DPP	BCL	DPP + BCP	BCP	IoT + BCP	IoT + BCL	DIH
Firm Size	Medium (Berger et al., 2023; Ghobakhloo et al., 2022)	Medium (Iva Kovacic et al., 2024; Chen, 2024)	High (Kühn et al., 2025; Bernier et al., 2024; European Union, 2022)	High (Winter et al., 2023a; Bernier et al., 2024; Pedone et al., 2021)	High (Sonar et al., 2024; Chen, 2024; Hader et al., 2022)	High (Mbavarira & Grimm, 2021; Cahn et al., 2023; Hernández-Chover et al., 2022)	Medium (Orko & Lavikka, 2023; Rosa & Terzi, 2023)
Digital Maturity Tier	High (Namagembe & Mbago, 2023; Ma et al., 2022; Farace & Tarabella, 2024)	Medium (Liu et al., 2021; Wuni & Shen, 2022)	High (Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	High (Pedone et al., 2021; Rosa & Terzi, 2023; Winter et al., 2023a)	High (Chen, 2024; Sonar et al., 2024; Hader et al., 2022)	Medium(Cahn et al., 2023; Hernández-Chover et al., 2022; Mbavarira & Grimm, 2021)	High (Rinaldi et al., 2022; Yu et al., 2022)
System Interoperability	High (Farace & Tarabella, 2024; Ma et al., 2022; Hader et al., 2022)	High (Liu et al., 2021; Wuni & Shen, 2022; Chen, 2024)	High (Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	High (Pedone et al., 2021; Bernier et al., 2024; Rosa & Terzi, 2023)	High (Mbavarira & Grimm, 2021; Cahn et al., 2023; Hernández-Chover et al., 2022)	Medium(Chen, 2024; Hader et al., 2022; Sonar et al., 2024)	High (Orko & Lavikka, 2023; Rosa & Terzi, 2023)
Financial Slack	Medium (Ma et al., 2022; Battistoni et al., 2023)	Low (Liu et al., 2021)	Medium (Berger et al., 2023; Kühn et al., 2025)	Medium (Rosa & Terzi, 2023; Pedone et al., 2021)	Medium (Cahn et al., 2023; Hernández-Chover et al., 2022)	Low (Chen, 2024)	Low (Kazancoglu et al., 2022)
Leadership Openness	High (Namagembe & Mbago, 2023; Ma et al., 2022; Sonar et al., 2024)	High (Pedone et al., 2021; Rosa & Terzi, 2023; Winter et al., 2023a)	High (Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	High (Rinaldi et al., 2022; Yu et al., 2022; Kazancoglu et al., 2022)	High (Chen, 2024; Hader et al., 2022; Sonar et al., 2024)	Medium (Cahn et al., 2023; Mbavarira & Grimm, 2021)	Medium (Orko & Lavikka, 2023; Rosa & Terzi, 2023; Hernández-Chover et al., 2022)
Workforce Data Skills	Medium (Battistoni et al., 2023; Kazancoglu et al., 2022)	Medium (Pedone et al., 2021; Rosa & Terzi, 2023)	Medium (Berger et al., 2023; Kühn et al., 2025)	High (Rinaldi et al., 2022; Yu et al., 2022; Kazancoglu et al., 2022)	High (Chen, 2024; Hader et al., 2022; Sonar et al., 2024)	Low (Cahn et al., 2023)	Medium (Hernández-Chover et al., 2022; Mbavarira & Grimm, 2021)
Network Embeddedness	Medium (Namagembe & Mbago, 2023; Farace & Tarabella, 2024)	Medium (Liu et al., 2021; Wuni & Shen, 2022)	Medium (Berger et al., 2023; Kühn et al., 2025)	High (Pedone et al., 2021; Rosa & Terzi, 2023; Winter et al., 2023a)	High (Chen, 2024)	Medium (Cahn et al., 2023; Mbavarira & Grimm, 2021)	Low (Hernández-Chover et al., 2022)
Regulatory Pressure	High (Berger et al., 2023; Kühn et al., 2025; Orko & Lavikka, 2023)	High (Liu et al., 2021; Wuni & Shen, 2022; Chen, 2024)	Medium(Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	Medium (Pedone et al., 2021; Rosa & Terzi, 2023)	Medium (Mbavarira & Grimm, 2021; Cahn et al., 2023; Hernández-Chover et al., 2022)	Medium (Chen, 2024; Hader et al., 2022)	High (Rinaldi et al., 2022; Yu et al., 2022)
Market & Consumer Pull	High (Namagembe & Mbago, 2023; Sonar et al., 2024; Farace & Tarabella, 2024)	High (Pedone et al., 2021; Rosa & Terzi, 2023; Winter et al., 2023a)	High (Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	High (Rinaldi et al., 2022; Yu et al., 2022; Kazancoglu et al., 2022)	High (Chen, 2024; Hader et al., 2022; Sonar et al., 2024)	High (Cahn et al., 2023; Mbavarira & Grimm, 2021)	Medium (Orko & Lavikka, 2023; Rosa & Terzi, 2023)
Standards Maturity	High (Ma et al., 2022; Berger et al., 2023; Orko & Lavikka, 2023)	High (Liu et al., 2021; Wuni & Shen, 2022; Chen, 2024)	High (Berger et al., 2023; Kühn et al., 2025; Bernier et al., 2024)	High (Pedone et al., 2021; Rosa & Terzi, 2023; Winter et al., 2023a)	High (Mbavarira & Grimm, 2021; Cahn et al., 2023; Hernández-Chover et al., 2022)	Medium (Chen, 2024; Hader et al., 2022)	High (Rinaldi et al., 2022; Yu et al., 2022; Kazancoglu et al., 2022)
Ecosystem Support	Medium (Battistoni et al., 2023; Kazancoglu et al., 2022)	Medium (Pedone et al., 2021; Rosa & Terzi, 2023)	Medium (Berger et al., 2023; Kühn et al., 2025)	High (Rinaldi et al., 2022; Yu et al., 2022; Kazancoglu et al., 2022)	High (Chen, 2024; Hader et al., 2022; Sonar et al., 2024)	Medium (Cahn et al., 2023; Hernández-Chover et al., 2022; Mbavarira & Grimm, 2021)	High (Orko & Lavikka, 2023; Rosa & Terzi, 2023; Hernández-Chover et al., 2022)

Figure C.2: Reference for mapping

D Interviews

D.1. Interview consent form

Figure D.1: Informed Consent Form for Interview Participants

Informed Consent Form

You are being invited to participate in a research study titled "Designing a Context-Aware Framework for SMEs to Select Suitable Information-Sharing Systems for Circular Business Activities." This study is being conducted by Pranav S, a Master's student at TU Delft, Faculty of Technology, Policy and Management, under the supervision of Dr. Jolien Ubacht (chair and first supervisor). This research is part of the graduation thesis for the MSc Management of Technology programme.

The research aims to develop a *context-aware decision-support framework that helps Small and Medium-Sized Enterprises (SMEs) select appropriate information-sharing solutions tailored to their specific digital, organizational, and regulatory contexts*. The interview will take approximately 30–45 minutes and is intended to help validate and refine the initial framework developed through literature and policy review.

You will participate in a semi-structured interview where we will discuss your professional experiences or expertise in circular business models, digital infrastructure, SME operations, or sustainability compliance. Your participation is voluntary, and you may choose to skip any questions you are not comfortable answering. With your consent, the interview will be recorded and transcribed. A summary will be prepared and anonymized, and you will receive a copy to reviewYou may suggest edits before your input is used in the thesis.

The data collected may also be reused for future academic research or educational purposes, but in all cases, your anonymity will be strictly protected. All personal data will be stored securely using TU Delft's institutional OneDrive system, and access will be restricted to the research team only.

While all necessary precautions will be taken to ensure confidentiality and data protection, please note that—like any online process—there is a minimal risk of data breach. However, no personal identifiers such as your name or organization will appear in any public report or thesis output.

Your participation is entirely voluntary, and you can withdraw at any time. If you choose to withdraw, you may request the removal of your data within one week of the interview.

I have read and understood the information above, and I consent to participate in the study and to the data processing.

If you have any questions about this study or your rights as a participant, please contact:

Participant:
Name:
E-mail:
Date:

Corresponding Researcher:
Name: Pranav Subramanian
E-mail: p.subramanian@student.tudelft.nl
Date: 16/04/2025

Responsible Researcher:
Name: Dr. Jolien Ubacht
E-mail: j.ubacht@tudelft.nl
Date:

Figure D.2: Message to Participant

Hi [Participant],

Hope you are doing well.
I'm a Master's student at TU Delft (Faculty of TPM), currently working on my MSc thesis in Management of Technology. My research aims to develop a decision-support framework to help SMEs select the most appropriate digital technologies—such as traceability platforms, IoT, or blockchain—based on contextual factors like regulatory pressure, data standards, and ecosystem maturity.

The goal is to make technology adoption for circular economy transitions more accessible and practical for SMEs. Given your companies work and your expertise in [relevant field], I believe your perspective could add significant depth to this framework.

Would you be open to a short conversation to discuss and evaluate the framework from your viewpoint at your earliest convenience?

Best regards,
Pranav Subramanian

D.2. Message Sent To request for Interview

D.3. Interview Questions

This appendix outlines the semi-structured interview guide developed to validate the relevance, usability, and completeness of the context-aware conceptual framework presented in this thesis.

The questions directly map to one or more sub-research questions, ensuring methodological consistency and conceptual traceability. The questions are intended to provide insights into the real-world resonance of contextual factors derived in Sub RQ2, and the perceived utility of the technological archetypes and mapping logic formulated across Sub RQ1 and Sub RQ3. Furthermore, the semi-structured format enables participants to contextualize their responses based on sectoral expertise and organizational roles. Initially, the interviewee was asked for a small introduction with asking about the company and what they do. After which the thesis was explained, showing the mapping created in chapter 5, and then the definition of each contextual factor. Then the following Questions were asked:

- After reviewing the above list and descriptions of the contextual factors included in the framework, do you find the terminology and definitions sufficiently clear and understandable from an SME or technology provider perspective? Are there any factors where the meaning or scope is ambiguous or could be improved?
- Based on your knowledge and experience, do these contextual factors reflect the key real-world considerations that SMEs typically face when evaluating or adopting digital tools for circular economy implementation? Are there any listed that seem unnecessary or less relevant in practice?
- Are there any important factors, conditions, or business environment characteristics you feel are missing from the framework—elements that could critically influence an SME's decision to adopt certain technologies but are not currently represented?
- Considering the full set of contextual dimensions and the way they are used to recommend technological archetypes, does the framework appear logically complete? In your view, does it offer a coherent structure that SMEs could follow to reach meaningful technology adoption insights?
- Do you believe the framework in its current form is usable by SMEs in practice? Could it serve as a conceptual tool or conversation starter in a strategic or implementation context? Are there any practical barriers to its adoption that you can foresee?
- Please add any more feedback or any other information you have:

D.4. Anonymized summary of Company A's interview

The semi-structured interview was conducted with a member of Company A, a Dutch startup operating in the sustainable flame retardant sector, to validate the practical applicability and clarity of the proposed context-aware conceptual framework for SME digitalization and circularity. The interviewee found the majority of contextual factors relevant and easy to understand, particularly after definitions were clarified, with "regulatory pressure," "digital maturity," and "ecosystem support" highlighted as most pertinent to their business context. Some terms, such as "financial slack," required additional explanation, and it was suggested that simpler language could further enhance accessibility. The interviewee regarded the mapping logic and the low/medium/high (LMH) scoring system as fundamentally logical but observed that the abstraction level might be high for startups or very small SMEs; for such companies, the urgency and value of investing in comprehensive frameworks is often outweighed by time and resource constraints. As a company grows and faces more complex challenges, the framework's utility increases, and it could serve as a valuable conceptual or checklist tool for larger SMEs. The expert also recommended simplifying the framework by grouping the eleven contextual factors into broader themes—product, market, legal, team, and financial—to aid comprehension and adoption. Overall, the feedback was constructive, emphasizing the importance of demonstrating clear value and practical guidance for SMEs, especially those with limited resources. All comments were anonymized following TU Delft's HRE C and DMP guidelines, and the summary reflects only non-identifying, thematic insights for potential future research and framework refinement.