Design Principles for IT-Driven Circular Economy Initiatives

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Abstract. The concept of the circular economy (CE) has gained widespread attention in academia, practice, and policy over the past decades. However, its implementation poses significant challenges, including diverse interpretations and a lack of conceptual clarity. These challenges hinder both research and practice, making it difficult for organizations to identify IT-driven CE initiatives and for researchers to build on a consistent foundation. We propose design principles that codify actionable design knowledge for IT-driven CE initiatives. Using a mixed-methods approach, we conducted a structured literature review, a quantitative and qualitative text analysis, and a nominal group workshop to identify three design principles, offering actionable design knowledge for practitioners and a structured foundation for researchers. The proposed design principles provide guidance on identifying and implementing IT-driven CE initiatives, thereby facilitating more effective and systematic adoption.

Keywords: Circular Economy, Design Principles, CE Principles, Sustainability, Mixed-Methods

1 Introduction

Despite its widespread use [1], the circular economy (CE) concept suffers from a significant lack of conceptual clarity, stemming from a large number of scientific definitions [2]. This ambiguity is not just an academic debate; it poses great challenges for implementation [3, 4], with 50% of companies identifying the absence of a clear definition as a major obstacle to implementing IT-driven CE initiatives [5]. This uncertainty directly hinders the adoption of IT-driven CE initiatives, as 39% of organizations report difficulties in identifying suitable strategies [6]. Given that the potential of IT for advancing CE is not fully realized, it is essential to systematize existing knowledge.

Design principles address these issues by structuring prescriptive knowledge and detailing the specific goals, contexts, mechanisms, and actors involved in a phenomenon to make it actionable and applicable within sociotechnical systems [7]. This short paper aims to develop design principles to investigate the following research question: **RQ1:** *What are the design principles to identify and implement IT-driven circular economy initiatives?*

2 IT-Driven Circular Economy

The CE is a framework aimed at addressing global sustainability challenges by balancing environmental preservation with economic development [8]. At its core, CE seeks to retain the ecological and economic value of natural resources within the system for as long as possible, allowing nature sufficient time to regenerate. This is achieved by extending product lifespans, recycling materials for comparable or new applications, and encouraging reuse through retained ownership of products [9].

As an economic model, CE aims to minimize resource consumption, waste generation, and emissions by optimizing, slowing, and ultimately closing material loops [2]. Although widely considered a modern approach, CE's origins are traced back to Boulding´s [10] foundational concept. Over the past six decades, discussions around waste and resource management have evolved CE into a comprehensive framework, albeit with varying interpretations.

Since its early fragmented initiatives, CE has gained widespread recognition as a holistic framework addressing actors, products, components, and material flows across all stages of product lifecycles. CE offers the potential to tackle sustainability challenges, reverse ecosystem degradation, and harmonize economic development with environmental preservation [8]. CE creates opportunities for income generation and improved working conditions, enhancing its socio-economic appeal [11].

The success of the transition to a CE relies heavily on the availability and effective use of extensive information and data, a capability significantly enhanced by technological advancements. Today, over 50 billion sensors are connected to more than 20 billion economic assets, enabling real-time monitoring and data generation [3, 12]. This unprecedented integration of material and information flows along value chains offers an opportunity to accelerate the transition to CE. Harnessing this data holds transformative potential for achieving more efficient and sustainable resource management [13].

From an IS perspective, digital technologies act as both direct and indirect facilitators in shifting from a linear economic model to a CE [4]. Advances in IS enable resource monitoring and optimization, create feedback loops between end use and recycling, and integrate material and information flows throughout the value chain [4]. These developments build trust among supply chain actors and address socio-technical challenges associated with coordinating diverse stakeholders [14].

One of the most significant challenges in implementing IT-driven CE initiatives is ensuring the effective provision and utilization of information across the entire social and material value chain. Linking material and information flows is critical to enhancing resource utilization and facilitating seamless coordination among heterogeneous actors [3, 4].

3 Methodology

Our research aimed to develop design principles for IT-driven CE initiatives. To do this, we chose to use a sequential mixed-methods approach as proposed by Venkatesh et al. [15]. In this approach, quantitative and qualitative data collection is carried out in different phases, with the results of the earlier phase theoretically or empirically underpinning the later ones to increase the overall richness of the study. Such a mixed-methods approach exploits the complementary strengths and non-overlapping weaknesses of quantitative and qualitative methods to provide a holistic perspective on the phenomenon under study and to gain deeper insights into the interrelationships [15].

Literature Search: We used the approach of vom Brocke et al. [16] to identify the relevant literature. In this phase, we first identified a real-world problem motivating the research. We began by defining the scope of the search, incorporating a combination of synonyms for IT and CE, followed by a conceptualization of the topic. At first, we conducted a search (title, abstract, keywords) with the search term (("circular economy") OR ("circular model")) AND ("information system*" OR "green information system*" OR "green IT" OR "green information technolog*" OR ICT) using four databases: Scopus, ScienceDirect, EBSCOhost Business Source Premier, and AISeLibrary. This search resulted in a total of 1.777 hits. Only literature referencing IS or related concepts was considered. In addition, literature in which the CE played only a minor role was excluded. We focused on primary data only. Publications based solely on secondary analyses, such as literature-based studies, were excluded, while those including case studies on the CE were included.

At the end of this literature analysis and synthesis process, 118 publications were identified as relevant. A forward and backward search were then carried out on these publications. In this way, 75 additional relevant sources were identified. A total of 193 publications were thus identified as relevant for this study. These form the basis for the following quantitative and qualitative text analyses.

Quantitative Text Analysis: In the next phase, a quantitative text analysis was performed to extract keywords and phrases from a large corpus of documents [17]. Quantitative text analysis makes it possible to simplify the semantic complexity of the text, discover more efficient structures, and make classifications, which is important for further qualitative analysis and interpretation of the literature.

As part of the quantitative text analysis, natural language processing methods were used to identify and extract keywords and topics. These computational techniques allow for the automatic analysis and representation of the linguistic content of the text. Our approach to quantitative text analysis was based on the concepts of Grimmer & Stewart [17]. This procedure resulted in a list of 142.026 word stems with 10.551 unigrams, 93.217 bigrams, and 38.258 trigrams, which are mentioned two times or more.

Qualitative Text Analysis: The identified word stems were subjected to a detailed qualitative textual analysis carried out independently by two researchers. The sentences in which the words appeared in the publications were analyzed to capture the contextual meaning of the words for subsequent analysis. Following Grimmer and Stewart's [17] recommendations to exclude very rare word stems, we focused our analysis on the first 500 unigrams, the first 250 bigrams and the first 100 trigrams. This focus allowed for an efficient and meaningful analysis of the most common word stems. The results were then aggregated, and any discrepancies were discussed and resolved in a joint meeting.

Nominal Group Workshop: We concluded with a qualitative nominal group workshop, where ten practitioners with various professional backgrounds and company affiliations further refined the qualitative results and contextualized them in practical applications to identify the final DPs. The participants included two experts from the plastics industry, four professionals from the service sector, and four consultants specializing in digital sustainability. This iterative process ensured that the DPs were grounded in empirical evidence and aligned with real-world needs.

The nominal group workshop, a structured method for decision-making and consensus-building within a group, was based on the recommendations of Van De Ven and Delbecq [18]. In the beginning, one of the authors brought the participants up to the same level of knowledge by presenting the results from the qualitative and quantitative text analysis and the eleven identified clusters. The participants were then divided into two groups. Their task was to group the eleven clusters and assign suitable headings to the groupings that represent the final DPs. The two groups then presented their groupings to each other. In the final step of the workshop, the participants were asked to agree on an aggregated solution based on the groupings presented.

4 IT-Driven Circular Economy Design Principles

Based on the methodological approach, we identified eleven clusters for developing our DPs by extracting design-relevant information critical for identifying and implementing IT-driven CE initiatives from previous research. These clusters serve as the foundation for our meta-requirements (MRs) and our DPs, developed in collaboration with CE experts during a nominal group workshop. This approach led to the identification of seven MRs and three DPs (see Figure 1).

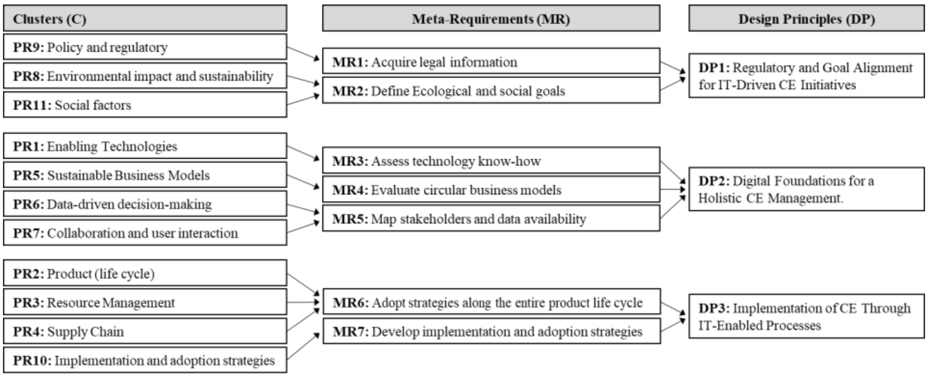

Figure 1. Mapping from clusters to meta-requirements and design principles.

DP1: Regulatory and Goal Alignment for IT-Driven CE Initiatives. This DP addresses two topics in IT-driven CE initiatives. First, it recognizes that decision-makers often lack specialized legal knowledge, leading to compliance risks and missed policy-driven opportunities [19]. Therefore, the system must (MR1) provide access to current regulatory frameworks. Second, it counters the common tendency to prioritize economic objectives at the expense of sustainability by (MR2) prompting decision-makers to define measurable ecological and social goals, ensuring that CE initiatives are balanced, compliant, and holistically sustainable [20].

DP2: Digital Foundations for a Holistic CE Management. This DP addresses three topics in IT-driven CE initiatives. First, it counters the underutilization of existing assets by (MR3), prompting organizations to document their current IT-driven CE technologies implemented and internal expertise [3, 4]. Second, it provides (MR4) a structured framework, using criteria like the Circularity Matrix, to systematically evaluate the feasibility and value-recovery potential of CE business models, ensuring adopted initiatives are both impactful and viable [21]. Finally, it closes information and collaboration gaps by (MR5) guiding decision-makers to map their stakeholders and the data available across the value chain [21].

DP3: Implementation of CE through IT-Enabled Processes. This DP highlights two main requirements: First, it mandates (MR6) a comprehensive, closed-loop approach by guiding decision-makers to select and integrate specific strategies, such as those from the 9R framework, across the entire product life cycle to maximize resource efficiency [22]. Second, it counters the failure of generic approaches by (MR7) demanding the development of concrete implementation and adoption strategies, which are critical for overcoming specific organizational barriers and ensuring the engagement of all stakeholders.

5 Discussion

This paper contributes to the discussion on IT-driven CE initiatives in academia and practice. By providing codified design knowledge in the form of DPs for IT-driven CE initiatives, this paper forms the foundation for future design theories while promoting the mediation of practice-oriented developments of artifacts in IS research, which is necessary for a well-founded scientific discourse on the topic [23].

Through the codified domain knowledge embedded in the proposed DPs, this study helps address the uncertainties surrounding the definition of CE, which many organizations have identified as a significant barrier to their implementation [5]. Furthermore, the proposed DPs support practitioners in overcoming conceptual uncertainties that hinder the identification of suitable IT-driven CE initiatives [6]. By offering structured design knowledge, DPs clarify what actions should be taken and provide guidance on how to implement these strategies effectively, enabling organizations to identify better and realize IT-driven CE initiatives.

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