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Abstract

A Circular Economy's (CE) adoption and continuation depend on various success factors, such as suitable collaboration between value chain stakeholders to enable circular material flows. Using digital platforms appears promising, as various CE use cases show. However, a differentiated view of the underlying mechanisms, i.e., the inherent characteristics and functionalities of digital platforms, is required to understand how these impact CE success factors and constitute the foundation for practical applications. Through a systematic literature review, we identified 15 digital platform mechanisms that impact 20 success factors for CE adoption and continuation. We conceptualized two CE platform types, each characterized by specific mechanisms: CE transaction brokers serve as marketplaces for resource trading. CE operating systems form technical supply chain infrastructures for collaboration alongside material flows. Our findings expand the theoretical understanding of the relationship between digital platforms and CE success, thus facilitating informed decisions about their practical use.

Keywords: circular economy, digital platforms, barriers and enablers, success factors

Introduction

By establishing closed-loop supply chains, a Circular Economy (CE) seeks to minimize the negative environmental impact of increasing resource consumption and waste (Geng et al., 2019). However, obstacles hinder the widespread adoption of a CE, including factors such as corporate culture deficiencies, insufficient collaboration, and missing partnerships (Kirchherr et al., 2018). In contrast, beneficial conditions, such as appropriate business models and supply chain infrastructure, foster CE deployment (Lahane et al., 2022). Overcoming obstacles and promoting beneficial conditions are essential to drive CE adoption and ensure its successful continuation (Aloini et al., 2020).

Digital platforms, i.e., software-based infrastructures enabling interaction and value co-creation between interest groups (Hagiu, 2007), have emerged as a viable option supporting circular operations in different settings and serving different objectives, as illustrated by a variety of use cases: Digital platforms have been harnessed to facilitate, e.g., the return logistics of packaging materials (Lehner & Elbert, 2023), create marketplaces for buying and selling waste (Soares et al., 2023), and enable the sharing of clothing (Jain et al., 2022). In this regard, Ciulli et al. (2020) have conceptualized digital platforms as circular brokers by presenting their roles in food waste, such as connecting CE stakeholders by creating new links between them. Blackburn et al. (2023) conceived them as meta-organizations that orchestrate a CE stakeholders ecosystem to create value in circular business models. Nevertheless, existing studies often focus on specific application domains (Ciulli et al., 2020) or examine digital platforms from distinct perspectives, such as from a technical (Kovacic et al., 2020), organizational (Wu et al., 2023), or business model standpoint (Blackburn et al., 2023). While these perspectives emphasize certain benefits of digital platforms for a CE, they may overlook the interconnected requirements of a CE (Ritzén & Sandström, 2017).

Instead, holistic changes and integrated strategies are needed for a successful CE adoption and continuation and must be considered by digital platform solutions (Kirchherr et al., 2017). Specifically, CE success factors, as referred to in this article, are necessary measures that must be realized for the adoption and continuation of a CE, in particular, overcoming impeding barriers and promoting favorable enablers (Ritzén & Sandström, 2017; Tura et al., 2019). Such CE success factors include various cultural, financial, organizational, and technical aspects (Kirchherr et al., 2018; Pasqualotto et al., 2023). For example, the collaboration between supply chain stakeholders is a crucial CE success factor for enabling circular material flows (Aloini et al., 2020). Digital platform solutions must promote such CE success factors and, where these are lacking, help to facilitate them (Lahane et al., 2022).

Mechanisms driven by digital platforms' fundamental characteristics, such as technical and market-based infrastructure or functionalities such as value creation or governance (Hagiu, 2007; Hein et al., 2020; Tiwana et al., 2010), can promote the CE success factors. For example, governance is a fundamental mechanism of digital platforms for controlling the platform ecosystem (Hein et al., 2020; Tiwana et al., 2010), which is conducive to the orchestration of CE stakeholders (Blackburn et al., 2023). A holistic description of digital platforms must consider market-based, technical, and socio-technical mechanisms (Hein et al., 2020). Viewing digital platforms through a narrow lens, such as purely technical or organizational solutions, appears inadequate, as this may omit relevant mechanisms, thus limiting their potential and failing to cater to the complex and diverse requirements of a CE (De Reuver et al., 2018).

Synthesizing theoretical and application-oriented research is essential to fully understand the intricate mechanisms of digital platforms and their multifaceted impact on CE success factors (Antikainen, 2018). Various studies have investigated different application areas for digital platforms in a CE (Ciulli et al., 2020; De Bernardi et al., 2021; Franzè et al., 2023). A systematic analysis of existing research can reveal the different mechanisms through which digital platforms drive CE success factors and how use cases within a CE achieve benefits, thus contributing to their understanding and facilitating continuous development and optimization (De Reuver et al., 2018). Furthermore, it promotes the precise application of future digital platform use cases in a CE, leveraging the transparency of available mechanisms and their respective impacts on desired CE success factors (Ciulli et al., 2020). Therefore, we aim to answer the following research question: *How can digital platform mechanisms foster a circular economy?*

We conducted a Systematic Literature Review (SLR) following the guidelines of vom Brocke et al. (2009), to gather knowledge about digital platforms in the context of a CE. The findings from 44 included articles were coded according to Corbin & Strauss (1990), resulting in 15 digital platform mechanisms influencing 20 CE success factors. These mechanisms characterize the foundational capabilities of digital platforms operating in CE use cases, assuring beneficial effects by nurturing CE success factors (Ciulli et al., 2020). Two CE platform types were conceptualized based on these mechanisms, specifying the combinations in which the mechanisms can be employed in practice.

The subsequent sections provide the theoretical foundation for the circular economy and digital platforms (Sec. 2), explain the methodological approach (Sec. 3), present the identified concepts and relationships in the results section (Sec. 4), and finish in a discussion (Sec. 5) and conclusion (Sec. 6).

Theoretical background

Circular economy

At its core, a CE is characterized by ensuring the sustainability of resource flows, aligning input and output with regeneration rates, and fostering a beneficial relationship between nature and society (Suárez-Eiroa et al., 2019; Velenturf & Purnell, 2021). To achieve these goals, a CE pursues strategies such as closing, slowing, and narrowing resource flows, achieved through reusing, recycling, and reducing (3R framework) (Kirchherr et al., 2017; Y. Li et al., 2023; Suárez-Eiroa et al., 2019). Further concepts like recovery (4R), redesign, remanufacture (6R), and a wide range of principles, including rethinking, repairing, refurbishing, and repurposing (9R), enrich this framework (Demestichas & Daskalakis, 2020; Gronau et al., 2022).

The transition to a CE may face obstacles that impede the adoption and application of its principles (so-called barriers) (Kirchherr et al., 2018). These obstacles include, for example, a hesitant, conservative company culture and linear operations or uncertainty and doubts about the profitability and benefits of CE practices (Ritzén & Sandström, 2017). Conversely, certain factors can facilitate this transition (Sinha, 2022). Enablers, in line with driving forces and critical success factors, propel the implementation of CE principles (Aloini et al., 2020; Sinha, 2022). Collaboration between different stakeholders, e.g., customers, regulators, and companies from similar or different industries, commonly referred to as industrial symbiosis, plays a crucial role in the successful and inclusive adoption of CE principles (Aloini et al., 2020; Lahane et al., 2022). Similarly, utilizing appropriate information and communication technologies and adherence to digital standards can foster CE-aligned supply chain operations (Sinha, 2022).

Digital platforms

According to their mode of operation and forms of value co-creation, digital platforms are characterized as *transaction* or *innovation platforms* (Evans & Gawer, 2016; Gawer, 2011, 2014; Koskinen et al., 2019). Transaction platforms act as multi-sided markets facilitating transactions between actors, e.g., trading products on eBay (Evans & Gawer, 2016; Hagiu, 2007). Conversely, innovation platforms are modular software systems featuring an extensible software core (i.e., the platform core) (De Reuver et al., 2018). The platform core can be extended by modular software products (i.e., complements), using technical resources (i.e., technical boundary resources) such as application programming interfaces for additional functionality (Tiwana et al., 2010). Integrated platforms combine traits of transactional and innovative platforms, e.g., when complements are distributed through digital marketplaces, exemplified by Apple iOS (Evans & Gawer, 2016).

In all cases, the surrounding ecosystem plays a vital role in digital platforms (Hein et al., 2020). The digital platform ecosystem involves autonomous third parties (i.e., stakeholders), such as individuals and organizations, interacting via the platform (De Reuver et al., 2018). Value can arise from efficient interactions in transaction platforms or innovative extensions of the platform core in innovation platforms (e.g., useful third-party apps for Apple iOS) (Evans & Gawer, 2016; Hein et al., 2020). Platform owners can control these interactions by implementing governance mechanisms (Schreieck et al., 2016) and interacting with the potentially large number of stakeholders at an arm's length (Hukal et al., 2020). The platform owner can strategically orchestrate the ecosystem and foster generativity and network effects (Körppen & Bender, 2024). First, generativity describes the ecosystem's innovative capacity, e.g., new ideas that arise from the interaction among the stakeholders (Hein et al., 2020). Moreover, due to network effects, digital platforms become increasingly valuable as their user base expands (Hagiu, 2007). Direct network effects are evident when users of a specific type draw in more users of the same type (e.g., social networks). Indirect network effects come into effect when an increase in users of one type heightens the platform's desirability for a different user group (e.g., buyers and sellers on digital marketplaces) (De Reuver et al., 2018).

In the context of a CE, research focused mainly on how digital platforms can enable circular resource flows (e.g., exchange of waste) (Soares et al., 2023) or the transfer of information (e.g., material passports) (Hirota et al., 2023). Online-to-offline platforms, which are extensions of purely digital marketplaces, are gaining importance, particularly in the context of a CE (H. Li et al., 2018). These platforms incorporate physical transactions, which are particularly relevant when exchanging resources such as products and raw materials (Zeiss et al., 2021). It has also been argued that using digital platforms is conducive to CE principles, e.g., as sharing platforms to enable collaborative and intensified resource use (Zeiss et al., 2021). Finally, conceptualizations of digital platform approaches have been developed, e.g., as circularity brokers that connect missing links in supply chains (Ciulli et al., 2020) or as meta-organizations that orchestrate ecosystems of CE actors (Blackburn et al., 2023). This study synthesizes findings on digital platforms for a CE to assess the extent to which knowledge of digital platforms as information systems has entered applied CE research (Zeiss et al., 2021). Thus, this study provides avenues for future research and practical application of digital platforms in a CE.

Methodology

We applied a three-stage methodological approach to investigate the influence of digital platform mechanisms on CE success factors. We followed Wolfswinkel et al. (2013), who outlined how to conduct a concept-centric analysis of the data collected through an SLR. First, we derived CE success factors from the literature. Next, we executed the SLR on digital platform mechanisms to support a CE. We followed the guidelines of vom Brocke et al. (2009), to ensure a careful selection of relevant literature on digital platforms for a CE. The analysis of the collected articles then followed the coding methods of Corbin & Strauss (1990), analogous to Wolfswinkel et al. (2013), to identify the mechanisms of digital platforms. In the third step, we applied the deductive coding method described by Elo & Kyngäs (2008) to explore the impact of these digital platform mechanisms on the previously identified CE success factors.

Planning and preparation

Extensive research has provided insights into the essential success factors for transforming traditional economic and business processes towards a CE (Govindan & Hasanagic, 2018; Kirchherr et al., 2018; Tura et al., 2019). On the one hand, barriers that prevent the implementation of CE principles in economic and operational processes are often emphasized and must therefore be adequately addressed by potential solutions (Kirchherr et al., 2018). On the other hand, favorable factors, often referred to as enablers, drivers, or critical success factors by previous studies, are considered to promote the adoption and successful continuation of a CE (Lahane et al., 2022). Overall, such factors are decisive for adopting and continuing a CE (Tura et al., 2019), which is why we refer to them as CE success factors in this study.

To answer the question of how digital platform mechanisms foster a CE, we needed a comprehensive understanding of the CE success factors identified in previous research. We therefore drew on influential studies that had already analyzed these factors to establish a well-grounded basis for answering our research question and to ensure consistency with the existing state of research. We searched databases such as Scopus, Web of Science, EBSCOHost Business Source Premier for related concepts such as "barriers", "enablers" and "drivers" in combination with "circular economy" to identify relevant literature on CE success factors. We consolidated influential studies (especially high citation counts) and studies that had already conducted literature analyses on such CE success factors (De Jesus & Mendonça, 2018; Geng et al., 2012; Govindan & Hasanagic, 2018; Kirchherr et al., 2018; Ritzén & Sandström, 2017; Tura et al., 2019). For instance, Kirchherr et al. (2018) identified 15 barriers. Tura et al. (2019) identified 18 drivers and 18 barriers. Govindan & Hasanagic (2018) identified 13 drivers and 39 barriers. Ritzén & Sandström (2017) identified nine barriers in the literature and five additional barriers through expert interviews. Aloini et al. (2020) identified 14 drivers and 13 success factors. Lahane et al. (2022) identified and ranked 43 enablers, while Sinha (2022) analyzed seven enabler classes. Pasqualotto et al. (2023) identified ten classes of drivers and barriers. In total, we identified 159 barriers, i.e., unfavorable factors, and 126 enablers, i.e., favorable factors for CE adoption and continuation, in the literature.

We consolidated the identified factors to eliminate redundancy and ensure their usefulness for subsequent analysis. First, we compared the individual barriers and enablers in terms of content to combine related elements. For example, Pasqualotto et al. (2023, p. 12) recognise "the collaboration between organizations and the enlarging of the network and partnerships" and Aloini et al. (2020, p. 7) mention "collaboration and coordination with external stakeholders" as enabler for CE adoption, which we have grouped together as the enabler "Partnerships and collaboration between stakeholders". On the other hand, Kirchherr et al. (2018, p. 266) identified a "Hesitant company culture" and Ritzén & Sandström (2017, p. 9) identified a lack of organisational "Attitude and knowledge" about a CE as a barrier, which we synthesised as "Lack of an appropriate corporate culture or willingness to change". In total, this resulted in 23 barriers and 18 enablers. Second, we found an overlap between barriers and enablers, suggesting that the absence of a barrier often acts as an enabler. For instance, it was found that an inappropriate corporate culture hinders the introduction of a CE (Kirchherr et al., 2018). At the same time, an appropriate corporate culture was recognized as an enabling factor (Aloini et al., 2020; Lahane et al., 2022). Ritzén & Sandström (2017) suggest that the lack of information exchange is a barrier, as Pasqualotto et al. (2023) argue that appropriate information exchange drives CE adoption. The examples show that these overlaps between enablers and barriers are not contradictory. They are merely the result of different perspectives but share an underlying meaning, which is why we have merged these semantic overlaps. This resulted in 20 success factors for CE adoption and continuation (Table 1).

Table 1. Success factors for CE adoption and continuation

Category	Id	CE success factors
Cultural	C1	CE-oriented company culture, business ethics or willingness to change
	C2	Consumer demand and consumption behavior for sustainable offerings
	C3	Public and consumer awareness about CE or willingness to change
	C4	Social pressure due to environmental concerns and burdens
	C5	Social and societal benefits through circular innovation
Financial	F1	Financial support, funding, and fiscal support for CE endeavors
	F2	Investment and operational cost and risk reduction potentials through circular operations
	F3	Business opportunities, profitability, and economies of scale achievable through a CE
Organi-zational	O1	CE-oriented business models and strategies
	O2	CE-oriented consumer engagement and market approach
	O3	Supply chain configurations, infrastructure, and practices supporting circular practices
	O4	CE-focused collaboration between supply chain stakeholders
	O5	Identification and forming of CE-oriented partnerships
	O6	Organizational responsibilities and integrated efforts for CE operations
Knowledge	K1	Suitable knowledge, skills, or engagement of supply chain stakeholders for a CE
	K2	CE-oriented knowledge, information, and data management and exchange
	K3	Transparency about CE activities, and appropriate evaluation methods
Technolo-gical	T1	Suitable information and communication technologies for supporting CE operations
	T2	CE-oriented solutions for utilization of secondary materials and environmental benefits
Regulatory	R1	Regulatory guidance and support for CE operations

Data collection

We conducted an SLR following the guidelines of vom Brocke et al. (2009) to collect relevant literature on digital platforms in the context of CE. Databases such as Scopus, Web of Science, EBSCOHost Business Source Premier, which lists multidisciplinary research, ACM digital library, and IEEE Xplore with more technical findings were included in the search, as Gusenbauer and Haddaway (2020) suggest. These databases were queried using the search string *"circular" AND "digital PRE/2 platform"* for hits in the abstract, title, and keywords. We used the proximity operator (PRE/2) only for databases that supported its application. The use of *"circular"* instead of *"circular economy,"* as well as the use of the proximity operator, allowed us to detect a variety of research articles (e.g., articles that only listed *"circularity"* or *"digital business platform"*) minimizing the risk of missing relevant articles. The search was carried out in November 2023 and all articles up to this date were included. We excluded articles not written in English or German and not published in peer-reviewed journals, conferences, or scientific books to ensure the scholarly rigor of the results. We screened the titles and abstracts of the articles to include articles addressing digital platforms related to the circular economy. This procedure resulted in 75 articles being included. Subsequently, we performed a full-text screening. We only included studies that provided details on the use of digital platforms in the context of CE to conclude their mechanisms and influence on the success factors of CE. Overall, we included 44 papers in the final body of literature (Figure 1).

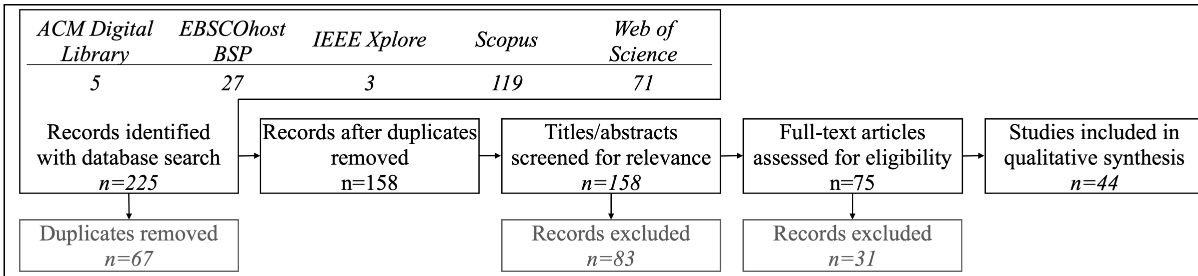

Figure 1. SLR review process

Data analysis and reporting

We coded the collected data according to Corbin & Strauss' (1990) approach to identify the digital platform mechanisms and their impact on CE success factors. Digital platform mechanisms encompass, in particular, fundamental characteristics or functionalities of digital platforms that facilitate interactions, activities or processes that are specific to digital platforms (Hein et al., 2020). These mechanisms cover market-based, technical, and socio-technical dimensions to support effective operation of the digital platform and to create value for its users in diverse forms (De Reuver et al., 2018; Tiwana et al., 2010). Inductive coding, using open, axial, and selective coding, facilitated the identification of digital platform mechanisms to extract patterns and provide generalizable evidence (Corbin & Strauss, 1990). As an example, Lehnert and Elbert (2023, p. 793) state that "The use of the platform *brings together actors* [a] from different sectors, which creates the *possibility of collaboration across different supply chains* [b]." Initially, we extracted the open code "connecting" from [a]. We then grouped open codes representing similar concepts into an overarching axial code. In this context, we consolidated the open code "connecting" with "matching" and "networking" under the axial code "Providing opportunities for connectivity." Following this, we introduced selective codes to logically integrate and group the axial codes (Wolfswinkel et al., 2013). The case was labeled as the selective code "Intermediary actions and orchestration of the ecosystem."

Furthermore, we used the previously identified collection of CE success factors (Table 1) to analyze how the digital platform mechanisms affect CE adoption and continuation. Specifically, this collection and the associated descriptions from the underlying literature were used as a code set to deductively encode the text passages of the SLR (Elo & Kyngäs, 2008). Since Lehnert and Elbert (2023, p. 793) mention in the preceding example that the digital platform mechanism "creates the *possibility of collaboration across different supply chains* [b]", we have deductively coded [b] as CE success factor *O4*, as this is consistent with the corresponding description of this CE success factor, such as that given by Aloini et al. (2020) (cf. section Planning and preparation). Overall, through inductive and deductive coding, we could identify the mechanisms of digital platforms and their impact on CE success factors. The example thus suggests that "Providing opportunities for connectivity" (digital platform mechanism) facilitates "CE-focused collaboration between supply chain stakeholders" (CE success factor).

We performed this coding procedure for all relevant text passages of the body of literature collected in the SLR (Wolfswinkel et al., 2013). To ensure the consistency of the coding and to exclude possible biases, all authors coded and checked the text passages iteratively. Coding 363 text passages containing platform mechanisms revealed 664 relations with CE success factors. This process yielded 15 axial codes and five selective codes described in the results.

Finally, following Wolfswinkel et al.'s (2013, p. 52) suggestion of "logical reasoning and cognitive pattern recognition," we revisited the individual studies in which the mechanisms occurred to understand the combinations and circumstances in which they emerge. Mossali et al. (2020), for example, outline a digital platform that focuses in particular on technical and functional mechanisms, suggesting similarities with the digital platform concepts proposed by Kovacic et al. (2020) and Rajala et al. (2018). In contrast, Lehner & Elbert (2023), De Bernardi et al. (2021) and De Jong & Mellquist (2021), for example, exhibit significant consensus on the mechanisms for matchmaking and marketplace transactions. We iterated between the mechanisms and existing literature to develop a theoretical model that illustrates in which combinations the mechanisms can manifest as specific CE platform types.

Results

Table 2 presents an overview of the identified digital platform mechanisms and their relevance for CE success factors. Descriptions of the individual mechanisms below explain how they influence CE success factors. Effects on CE frequently found in the literature are highlighted, indicating the corresponding importance of the cause-effect relationship (Helfat, 2007). Less frequently considered interdependencies are also presented, as these could exemplify concealed potential for practice and possible future research directions. The effects outlined in the text are connected to the relevant CE success factors by using the identifiers in brackets.

Table 2. Digital platform mechanisms and their impact on CE success factors

Digital platform mechanisms	CE success factors																			
	C1	C2	C3	C4	C5	F1	F2	F3	O1	O2	O3	O4	O5	O6	K1	K2	K3	T1	T2	R1
Provision of a shared information and communication system																				
Providing a technological basis	1	2	2				2	4		1	5	9	1			22	6	21	2	2
Providing operational functions		1	1				2	3		1	6		2			1		9	2	
Providing reporting functions	1	1	2				4	2	2	1	3	6	2			11	12	6	1	1
Governance and control of digital platforms																				
Implementing formal structures								2	6	2	1	2		1				3		
Establishing and controlling regulations								1										3		5
Determining the degree of openness	2	2	2					3		1	1	2	2			3	1	4		1
Cultivation of a stakeholder ecosystem																				
Granting the stakeholders autonomy		2	2		1		1	1		1	1	2	2			1	1	1		
Providing multi-sided access										2	3	10					1			3
Scaling of the ecosystem size	2	1	2					4		2		4	3							
Intermediary actions and orchestration of the ecosystem																				
Providing opportunities for connectivity	1	2	2				2	9		1	2	9	21			2	1	5	1	1
Organizing joint interactions		3	3		2		5	6	4	6	12	6		1		3	3	6	8	
Offering awareness and education	4	3	3					5	3	1		3	1		6	5		2	1	
Fostering value co-creation of the ecosystem																				
Enabling the exchange of data and information	2	1	2				2	1		1	3	15	2			12	1	3	2	
Fostering actor innovation and generativity	1	2	1				2	5	1	1		10	2			2		3		
Enabling functional expandability																	1	4		

Notes. The numbers and corresponding color gradings describe the quantity of individual papers that emphasize a relation between digital platform mechanism and CE success factors.

Provision of a shared information and communication system

Providing a technological basis. Digital platforms can function as comprehensive databases for integrating heterogeneous data from diverse sources, notably supply chain stakeholders (Beguedou et al., 2023; Hirota et al., 2023; Soldatos et al., 2020). Consequently, they can foster CE success factors regarding shared data management *(K2)* (Kovacic et al., 2020; Soares et al., 2023) and collaboration and partnerships *(O4)* (Franzè et al., 2023; Jain et al., 2022). For the storage and use of integrated data, digital platforms can employ innovative and specialized technologies (Choudhuri et al., 2023; Huynh & Rasmussen, 2021). For instance, blockchain-based platforms foster CE-related behaviors and willingness *(C1-C3)* by providing transparency and trust regarding material origins and properties through decentralized data storage (Darwish, 2023; Jain et al., 2022; Q. Li & Wang, 2021).

Digital platforms can be integrated with the relevant systems, such as Enterprise Resource Planning systems, or specialized technologies, such as digital twins and Internet of Things technology (Çetin et al., 2021; Stratmann et al., 2023; Talla & McIlwaine, 2022). Integrating these technologies into digital platforms is an appropriate mechanism to foster CE-related knowledge management *(K2)* (Çetin et al., 2021; Stratmann et al., 2023; Talla & McIlwaine, 2022). This integration reduces entry barriers for stakeholders (Beguedou et al., 2023; Blackburn et al., 2023), enhancing the efficiency of CE transactions and processes and thereby promoting collaboration *(O4)* (Ciulli et al., 2020; Demestichas & Daskalakis, 2020). For example, in construction, the deployment of Building Information Modeling platforms that leverage the Internet of Things and material passports offers stakeholders transparency about construction resources throughout their lifecycle, fostering circularity (Çetin et al., 2021). Moreover, platform-driven product-service systems, such as rental services for furniture, can unlock potential new business opportunities *(F2, F3)*, influence usage patterns (*C2*), and foster cost savings (*F2*) and environmental benefits (*T2*) through extended product lifecycles (Balder et al., 2023; Darwish, 2023).

Providing operational functions. A digital platform can offer essential functions for CE activities, which stakeholders can utilize (Blackburn et al., 2023; Kovacic et al., 2020). These functions can facilitate CE operations, such as optimizing waste transportation scheduling (Hirota et al., 2023; Wu et al., 2023), assessing the recyclability of materials (Achenbach et al., 2023), predicting demand (Hirota et al., 2022), as well as production planning *(T1)* (Mossali et al., 2020). The effectiveness of CE activities and process efficiency can thus be improved *(O3)*, unlocking environmental benefits and profitability potential *(F3)* (Pedone et al., 2020). Additionally, support functions of the platform, such as payment processes (Ciulli et al., 2020; Revinova et al., 2020) and the reconciliation of debts and claims (Lehner & Elbert, 2023), can be provided by digital platforms to minimize risks and streamline CE transactions for the participants *(F2)* (Hirota et al., 2022).

Providing reporting functions. Digital platforms can provide reporting functionality that facilitates environmental analyses (Ciulli et al., 2020), financial reporting (Pedone et al., 2020), process, material, and information flow tracking *(K3)* (Çetin et al., 2021). First, environmental analysis services, e.g., for calculation of the circularity level of objects (Lombardi et al., 2020), life cycle costs of transportation and storage of recycled material (Q. Li & Wang, 2021), information on saved CO2 (Wuyts et al., 2023) or waste (Dounavis et al., 2019), can encourage awareness, engagement, and appropriate CE behaviors *(C1-C3)* (Ciulli et al., 2020; Pizzi et al., 2022). Second, digital platforms can enable financial reporting, for example, on waste materials sold, to provide transparency on the profitability of CE activities *(F3)* (Ciulli et al., 2020). Third, monitoring material and information flows that pass through a digital platform can provide aggregated perspectives of events, e.g., through web-based visualizations (Soldatos et al., 2020; Talla & McIlwaine, 2022; Wu et al., 2023). These can inform reusability decisions (Q. Li & Wang, 2021), close information gaps between involved parties (Çetin et al., 2021; Jain et al., 2022), and thus enable closed-loop supply chains *(O3)* (Q. Li & Wang, 2021; Rajala et al., 2018).

Governance and control of digital platforms

Implementing formal structures. Digital platforms possess the capability to incorporate organizational structures (Stratmann et al., 2023), thus delineating the scope, procedures, responsibilities, and relationships among stakeholders involved in CE operations *(O6)* (Blackburn et al., 2023; Kovacic et al., 2020). These structures can facilitate the deployment of diverse for-profit and non-profit business models (Kovacic et al., 2020; Wuyts et al., 2023), enabling the configuration of a model suitable for CE purposes *(O1)* (Blackburn et al., 2023; Schwanholz & Leipold, 2020; Wuyts et al., 2023).

Establishing and controlling regulations. Control of interactions on digital platforms can assume various modalities: Standardized and formal agreements, rules, and policies are particularly noteworthy as they furnish stakeholders with regulatory backing and guidance in the context of CE interactions *(R1)* (Kovacic et al., 2020; Wu et al., 2023). Unwanted CE activities are systematically prohibited, while purposeful ones are actively encouraged (Blackburn et al., 2023). For example, implementing food safety rules on the digital platform mitigates risks and safeguards participants *(F2)* (Ciulli et al., 2020). Similarly, this may encompass prerequisites for engaging in circular transactions, such as licensing for buying or selling (Soares et al., 2023) or control over information access on the platform (Boukhatmi et al., 2023). Digitized public policy frameworks can integrate regulatory requirements into platform-based CE transactions *(R1)* (Kovacic et al., 2020; Wu et al., 2023).

Determining the degree of openness. The degree of openness in a digital platform is subject to various dimensions (Kovacic et al., 2020). Firstly, it determines the accessibility for CE stakeholders, ranging from closed systems relying on contractual relationships (Blackburn et al., 2023) to open systems that allow for flexible participation (Rajala et al., 2018). Access may be restricted to select organizations that align with the platform's scope, for instance, those providing food waste matching the demand (Ciulli et al., 2020). The degree of openness in a digital platform can foster meaningful engagement by CE stakeholders, eliminate inclusion barriers, and enhance their willingness to participate in CE ecosystems *(C1, C3)* (Del Vecchio et al., 2021; Lekan & Rogers, 2020). Greater openness can lead to the free flow of CE information *(K2)*, business opportunities, and platform growth *(F3)* (Rajala et al., 2018). Additionally, openness can foster unforeseen connections *(O5)* that may promote CE-oriented value chain configurations reliant on more flexible material exchange *(O3)* (Rajala et al., 2018). Conversely, more closed platform settings are conducive to profit capture, organizational information protection, enduring partnerships, and deeper collaboration *(O4)* (Rajala et al., 2018). Secondly, the degree of openness influences the stringency of input control, i.e., which products and services, such as types of food waste, may be offered on the platform (Ciulli et al., 2020). This input control can ensure compliance with specific sustainability and quality criteria for the offers and thus reduce the risks associated with their use *(F2)* (Achenbach et al., 2023; Balder et al., 2023). Lastly, the degree of openness regulates the accessibility of boundary resources, including digital interfaces for data access or the integration of complementary services (Kovacic et al., 2020). The openness of boundary resources allows for extending relevant CE functionality in the digital platform (Rajala et al., 2018). It facilitates the technical exchange of CE data (Kovacic et al., 2020), all while being subject to control to ensure adherence to rules and standards *(T1)* (Pedone et al., 2020).

Cultivation of a stakeholder ecosystem

Granting the stakeholders autonomy. Participants in a digital platform's ecosystem are frequently less tightly interconnected than in traditional business relationships (Wu et al., 2023). This looser coupling can enhance the willingness to participate and foster favorable behaviors of self-reliant actors involved within the platform ecosystem *(C2, C3)* (Charnley et al., 2022; Jain et al., 2022). In addition, actors have the autonomy to utilize the platform and its features for their objectives, for instance, in the context of selecting trading partners for transactions involving recycled materials (Ciulli et al., 2020; Jain et al., 2022; Pizzi et al., 2022).

Providing multi-sided access. A digital platform offers access to diverse CE stakeholders, e.g., manufacturers, end-users, and recyclers (Achenbach et al., 2023; Q. Li & Wang, 2021; Pizzi et al., 2022), potentially spanning one or more industries, e.g., construction and automotive (Mossali et al., 2020). Consequently, it supports inter-organizational use *(O4)*, enabling a shift from traditional linear value chain arrangements towards more suitable CE-oriented configurations *(O3)* (Çetin et al., 2021; Franzè et al., 2023). Moreover, it can be customer-facing, allowing for CE-oriented customer engagement and market strategies *(O2)* (Choudhuri et al., 2023) and giving access to regulators, resulting in efficient regulatory guidance for CE *(R1)* (Del Vecchio et al., 2021; Wu et al., 2023).

Scaling of the ecosystem size. Network effects, facilitated through multi-sided digital platforms, enhance the attractiveness of participation and incentivize actors to become part of the CE ecosystem *(C1, C3)* (Rajala et al., 2018). For instance, intensified collaboration from the public sector in waste recycling platforms can stimulate company engagement, as it streamlines the acquisition of governance services (Wu et al., 2023). Similarly, a broader array of CE services on the platform, such as those provided by plastic recyclers, can expand the customer base and stimulate demand *(C2)* (De Jong & Mellquist, 2021). Network effects can be stimulated by the platform owner, for instance, by serving one side of the platform himself (supplying CE resources or generating CE demand) (Blackburn et al., 2023; De Jong & Mellquist, 2021). In general, the growth of the platform-based CE ecosystem through network effects can give rise to circular value creation (Blackburn et al., 2023) and new business and revenue opportunities *(F3)* (De Jong & Mellquist, 2021). This expansion allows new partnerships and customer relationships *(O5)*, thus increasing the potential for suitable collaborations *(O4)* and fostering the creation of circular value and innovation *(F3)* (Ciulli et al., 2020).

Intermediary actions and orchestration of the ecosystem

Providing opportunities for connectivity. Digital platforms provide stakeholders with transparency and visibility concerning potential partners, simplifying their identification and the development of collaborative CE opportunities, partnerships, and networks *(O5)* (Achenbach et al., 2023; Balder et al., 2023). Supply and demand of circular products and services can be matched by identifying cross-organizational, cross-industry, and cross-regional synergies (Gentilini et al., 2020; Soldatos et al., 2020), possibly driven by preferences, e.g., related to material properties and availability (De Jong & Mellquist, 2021; Panza et al., 2022). This matching can expose the potential for collaborations that might have otherwise remained concealed *(O5)* (Balder et al., 2023). Organizations can, for example, identify new customers *(O5)*, such as those interested in food waste or second-life resources (Pedone et al., 2020). This may create new business opportunities and revenue streams *(F3)* (Boukhatmi et al., 2023) and reduce costs by preventing double marginalization or efficiently identifying optimal market deals *(F2)* (Franzè et al., 2023; Rajala et al., 2018).

Organizing joint interactions. By providing shared tools and technically implementing CE workflows, digital platforms can orchestrate collaborative material flows and processes along the supply chain, e.g., for reverse logistics of white goods *(T1)* (Ciulli et al., 2020; Wu et al., 2023). In addition, interactions can be orchestrated through control mechanisms, e.g., quality controls of products and services, certification of actors, or sanctioning misconduct (Lehner & Elbert, 2023). Consequently, more efficient supply chain interactions can be achieved (O3), resulting in resource conservation, e.g., by reducing consumer waste *(T2)* and cost reductions *(F2)* (De Bernardi et al., 2021; Ritala et al., 2023).

Moreover, digital platforms can employ market mechanisms, thus facilitating the trade of resources such as surplus materials, by-products, and waste (De Almeida Oroski & da Silva, 2023). Additionally, borrowing, renting, and resale of consumer goods, such as clothing, is supported (Ghoreishi & Happonen, 2022). Consequently, those platform-based digital markets may increase revenue through novel business opportunities *(F3)* (Beguedou et al., 2023; De Jong & Mellquist, 2021), reduce waste disposal costs *(F2)* (De Bernardi et al., 2021), and resource consumption, e.g., by preserving value through reuse *(T2)* (Lombardi et al., 2020).

Offering awareness and education. Through dedicated information and educational resources such as online courses, training programs, or consulting services, digital platforms can influence stakeholders' perceptions (*C3*) and foster the development of capabilities among CE stakeholders *(K1)*. Additionally, beneficial behaviors for a CE *(C2)* and the enhancement of CE solution design are promoted *(T2)* (De Bernardi et al., 2021; Demestichas & Daskalakis, 2020; Y. Li et al., 2023). Furthermore, the platform-based transfer of information and knowledge between stakeholders can achieve knowledge spillover *(K2)* (Del Vecchio et al., 2021). For example, some stakeholders' successful adoption of platform-based CE activities can demonstrate their usefulness, thus guiding others toward effective integration (Pizzi et al., 2022).

Fostering value co-creation of the ecosystem

Enabling the exchange of data and information. By providing an infrastructure for transactions among diverse stakeholders, digital platforms enable the structured exchange of data and information for CE operations *(K2)*, e.g., along product life cycles (Kovacic et al., 2020). By facilitating such an exchange, the effective coordination of circular practices is facilitated (*O3*) (Q. Li & Wang, 2021; Wu et al., 2023). Those, in turn, may give rise to communities and partnerships spanning across supply chains, sectors, and possibly encompassing multiple industries (Lombardi et al., 2020; Rajala et al., 2018), thereby enabling collaboration among CE stakeholders, thus fostering CE-oriented networks and industrial symbiosis *(O4)* (Çetin et al., 2021; Talla & McIlwaine, 2022). The active participation of society in CE-focused collaboration can augment social awareness and acceptance *(C1, C3)* (Wu et al., 2023). Moreover, by spreading relevant product information to customers via a digital platform, their involvement in a CE can be strengthened *(O2)* (Ghoreishi & Happonen, 2022).

Fostering actor innovation and generativity. By creating an ecosystem where different stakeholders interact, digital platforms promote generative mechanisms (Pizzi et al., 2022; Rajala et al., 2018). The ecosystem's emergent generativity can spawn new CE use cases, including innovative circular products and services (Khan et al., 2022; Kovacic et al., 2020), as well as the identification of circular supply chain routes and practices *(O3)* (Soldatos et al., 2020). Moreover, entrepreneurial CE initiatives can stem from this generativity (Del Vecchio et al., 2021), facilitating the development of novel CE business models *(O1)*, competitive advantages, and revenue streams *(F3)* (Beguedou et al., 2023; De Bernardi et al., 2021). Finally, the platform owner can benefit from the generativity of the ecosystem by outsourcing circular value creation, e.g., in the form of CE services, thus reducing his effort and costs *(F2)* (Charnley et al., 2022; Franzè et al., 2023).

Enabling functional expandability. Leveraging the boundary resources provided by the platform, stakeholders possess the capacity to expand the platform's functionality through the integration of modular services, consequently broadening the functional scope of the platform (Dounavis et al., 2019; Kovacic et al., 2020). Developing and integrating suitable third-party functionality into the platform can enhance the provision of stakeholder-specific and contextually relevant services, improving CE processes and decision-making *(T1)* (Franzè et al., 2023; Pedone et al., 2020). Moreover, such complementary functionality and services can be made available to other stakeholders so that they can also reap the benefits (Pedone et al., 2020).

Discussion

This literature review identified 15 digital platform mechanisms that impact various CE success factors. In particular, research emphasized the impact of digital platforms on collaboration between CE supply chain actors (*O4*), the provision of appropriate information and communication technologies (*T1*), and adequate knowledge, information, and data management and exchange (*K2*) (Pedone et al., 2020; Pizzi et al., 2022). Digital platform mechanisms providing multi-sided connectivity and a common technical infrastructure facilitate these success factors (Balder et al., 2023). In addition, platform-based transactions, e.g., data or resource exchange and orchestrated CE workflows, contribute to achieving these success factors as well (Boukhatmi et al., 2023).

Practical applicability hinges on the targeted combination of relevant mechanisms, facilitating meaningful use cases in a CE (Ciulli et al., 2020). Particularly considering a CE's extensive impact on comprehensive value chains and industries (Kirchherr et al., 2017), there are various areas in which solutions are needed to foster success factors (Antikainen, 2018). Different combinations of the mechanisms enable the versatile use of digital platforms (Rajala et al., 2018). To better grasp the contexts in which digital platform mechanisms occur and their practical significance, the following section discusses them against existing research on digital platforms in a CE and the theoretical background of digital platforms.

First, a research perspective considers digital platforms as virtual marketplaces, enabling, for example, the exchange of physical resources, such as various types of waste (Soares et al., 2023). Such platform-based virtual marketplaces can also facilitate transactions between consumers for reuse and sharing, e.g., of furniture and textiles (Balder et al., 2023; Charnley et al., 2022; Revinova et al., 2020). The digital platforms analyzed in these studies emphasize mechanisms to facilitate diverse transactions between CE stakeholders (Beguedou et al., 2023). Additionally, matching different stakeholders' supply and demand needs, thus creating synergistic opportunities and partnerships, is a crucial objective (Achenbach et al., 2023; Soares et al., 2023). Supplementary services, such as payment functions, streamline trading circular resources (Revinova et al., 2020). Finally, some studies also focus on exchanging knowledge and information between CE stakeholders through a digital platform, serving as a marketplace for intangible transactions (Del Vecchio et al., 2021). In this way, knowledge ecosystems can be established that enable innovation and collaboration between stakeholders (Del Vecchio et al., 2021). Strikingly, the digital platforms considered in these studies resemble traditional transactional platforms focusing on exchanging physical resources, information, data, and knowledge (Evans & Gawer, 2016; Gawer, 2011). Overall, since this CE platform type aims to connect CE stakeholders and facilitate transactions, regardless of whether they are resource- or knowledge-based, we conceptualize it as a ***CE transaction broker*** (Figure 2, left).

Secondly, some studies extend the perspective of platform-based virtual marketplaces to include more advanced technical and functional mechanisms. These studies also focus on the resource flows digital platforms can facilitate in a CE (Lehner & Elbert, 2023). However, unlike a pure marketplace, these studies often emphasize that digital platforms can enable a comprehensive infrastructure for interactions in the CE value chains (De Bernardi et al., 2021; Franzè et al., 2023; Wu et al., 2023). As a result, digital platforms are taking on an increasingly technical role, encompassing database, software, and function-based mechanisms (Kovacic et al., 2020). This involves the integration of data storage mechanisms, such as shared databases among multiple CE stakeholders, which may be coupled with other software systems like the Internet of Things or Enterprise Resource Planning systems (Stratmann et al., 2023). In addition, studies indicate how digital platforms offer stakeholders specific functionalities built upon the technical infrastructure to deliver customized benefits. Examples include operational planning functions for reverse logistics processes, monitoring material flows, or facilitating CE decisions (Franzè et al., 2023; Lehner & Elbert, 2023; Pedone et al., 2020). Some studies also mention that digital platforms can offer boundary resources, enabling CE stakeholders to extend functionality through customized software modules (Pedone et al., 2020). These studies depict digital platforms as having essential similarities to traditional transactional platforms by focusing on the exchange of data and resources (Lehner & Elbert, 2023; Ritala et al., 2023). However, by emphasizing an increasingly comprehensive software core and addressing the extensibility of this core, these descriptions of digital platforms are also consistent with innovation platforms (Tiwana et al., 2010). We conceptualize that a ***CE operating system*** is a common technical infrastructure for collaborative supply chain processes along the material flows (Figure 2, right).

Finally, some mechanisms are essential in both CE platform types and receive similar attention in their respective studies. The cultivation of stakeholder ecosystems and the implementation of governance and control mechanisms are of particular interest in research on digital platforms (Hein et al., 2020) and are increasingly being transferred to the CE sector (Blackburn et al., 2023; De Jong & Mellquist, 2021). In particular, the degree of openness is a relevant object of investigation to enable different uses of CE platform types in the CE context (Del Vecchio et al., 2021; Lekan & Rogers, 2020). This degree of openness can range from closed ecosystems that enable close partnerships in the supply chain to open marketplaces that offer complete autonomy to ecosystem stakeholders (Rajala et al., 2018). Additionally, both CE platform types can generate network effects, encouraging new stakeholders to engage with the platform and fostering promising interactions (Wu et al., 2023). Like traditional platform types, CE platform types can coexist and adapt to different use cases based on their respective objectives (Gawer, 2011; Rajala et al., 2018).

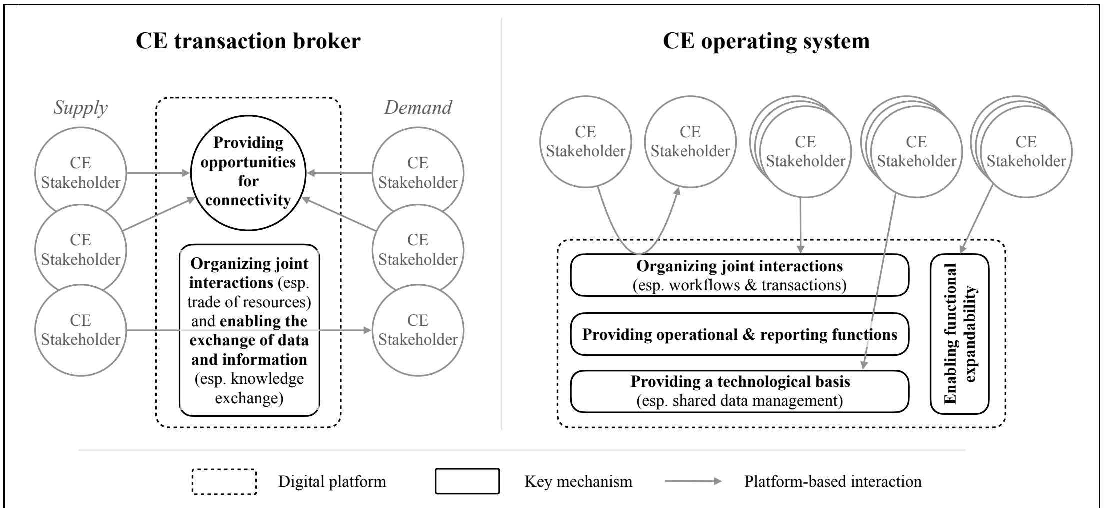

Figure 2. Conceptual model of the CE platform types

Theoretical and practical contribution

This study contributes to research on digital platforms for a CE. Previous research has delved into conceptual interpretations, such as viewing them as circularity brokers assuming diverse brokerage roles in CE (Ciulli et al., 2020) and meta-organizations employing different orchestration mechanisms (Blackburn et al., 2023). Rajala et al. (2018) presented three archetypes of CE ecosystems and considered, for example, their openness and forms of collaboration.

This study extends existing knowledge in two principal ways. First, various studies on digital platforms in the context of CE are systematically analyzed, identifying underlying mechanisms that illustrate how digital platforms deploy capabilities and functions in a CE and positively influence CE success factors. Second, this research introduces a novel conceptualization of digital platforms tailored explicitly for the CE domain. Notably, this conceptualization draws from the concrete mechanisms applied in the CE context and the theoretical background of digital platform research (Evans & Gawer, 2016; Gawer, 2011; Hagiu, 2007; Hein et al., 2020; Tiwana et al., 2010). As a result, it extends existing perspectives from research on digital platforms in the context of a CE, such as that of the circularity broker (Ciulli et al., 2020), by presenting two CE platform types that differ in terms of their mechanisms and thus allow for a more nuanced investigation in future research. This study is in line with the call of Zeiss et al. (2021) urge research to focus on how digital platforms can support complex collaborative processes along material flows and value chains rather than focusing solely on the matchmaking capabilities of digital platforms in a CE context. Anchoring the conceptualizations in tangible digital platform mechanisms provides a precise definition and transparency regarding their interplay with CE success factors.

On a practical level, this study contributes by abstracting and generalizing the application-oriented perspective, allowing for the transferability of research findings to various use case scenarios within the CE domain. We are responding to Ciulli et al.'s (2020) call for a generalized, cross-supply chain view. Such a generalized lens enhances the versatility of applying the mechanisms and CE platform types identified in the study. Thus, this research equips practitioners with tools to apply these mechanisms in purposeful CE platform types. This empowers organizations to exert deliberate control over the desired effects of their digital platform implementation.

Limitations and Future Research

In reviewing this study's findings and contributions, it is vital to recognize limitations and explore avenues for future research to deepen the understanding of digital platforms for a CE. Regarding the study design, we employed rigorous and well-established procedures (Elo & Kyngäs, 2008; Wolfswinkel et al., 2013; Zeiss et al., 2021). Strict exclusion criteria were applied in the literature review, particularly that articles should be peer-reviewed to ensure the results' quality. However, it cannot be ruled out that individual articles are of questionable rigor. Moreover, during this procedure, the saturation of identified mechanisms was attained, yet the study's scope was confined to literature obtained through a database search. Future expansion, through methods such as forward and backward searches, could enhance the understanding of underrepresented concepts. For example, research into complementary functionality, a proven cornerstone of innovation platforms (Tiwana et al., 2010), is only given limited consideration in the included studies. Additionally, research on control and governance mechanisms holds untapped potential, especially considering their fundamental role in digital platforms (Schreieck et al., 2016), as well as the need for appropriate regulations in supply chain and CE contexts (Kirchherr et al., 2018). We found little evidence of correlation with digital platform mechanisms for certain CE success factors, e.g., societal benefits such as public health and wellbeing. Future research could investigate these gaps to uncover concealed benefits for CE success factors.

Moreover, as reflected in the identified mechanisms and CE platform types, this study's conceptual and theoretical focus necessitates practically validating these concepts and interdependencies. This entails empirical examination of the mechanisms' effects on CE success factors and practical observations of CE platform types to validate their characterizations based on the mechanisms. In this context, it is worth investigating how external factors, such as the industry and supply chain focus of a digital platform for CE, affect the CE platform type and its mechanisms (Ciulli et al., 2020). Moreover, this could help to investigate whether the impact of digital platform mechanisms on CE success factors is industry-dependent. Overall, this could further advance their targeted applicability in practical scenarios.

Finally, although this study integrates theoretical principles from various fields, especially CE and digital platform research, it does not claim to be exhaustive in its development and definition of the CE platform types. To advance the development of digital platforms for a CE, it is advisable to incorporate established concepts (e.g., governance) from digital platform research and transfer established findings to the field of CE (De Reuver et al., 2018). Based on established platform typologies, the CE platform types developed in this study can serve as a basis for a well-founded transfer of knowledge from digital platform research and related disciplines.

Conclusion

This study examined the crucial role of digital platforms for a CE. An SLR and subsequent iterative coding of the research findings identified 15 distinct mechanisms through which digital platforms influence 20 CE success factors. The identified mechanisms underline that the versatility of digital platforms is widely applicable in a CE (Ciulli et al., 2020). For instance, market mechanisms (e.g., network effects and matching), organizational mechanisms (e.g., governance mechanisms), and technical mechanisms (e.g., technical basis) were identified (Kovacic et al., 2020; Wu et al., 2023). At the same time, the extensive effects on the multi-level CE success factors, e.g., in terms of cultural, organizational, and technical aspects, demonstrate how digital platforms can benefit the adoption and continuation of a CE (Antikainen, 2018).

Finally, reviewing the mechanisms in the light of prevailing research, two types of CE platforms emerged: CE transaction brokers, focusing on matching and transactions, and CE operating systems, offering technical and functional infrastructure for CE operations. These platform types highlight the varied combinations of mechanisms utilized in different CE scenarios and settings to enable diverse applications of digital platforms in a CE (Ciulli et al., 2020).

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