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Material-Traceability-as-a-Service: Positioning the role of digital product passports in realizing circular economy performance

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ABSTRACT

Industrial firms face growing pressure to reduce their material intensity and carbon emissions. The Circular Economy (CE) offers a promising pathway toward sustainable and regenerative practices, yet translating CE principles into actionable strategies remains complex. Despite increasing attention, little is known about how interdependent organizational and institutional conditions combine to deliver CE performance. This study addresses this gap by identifying configurational strategies for enabling circular outcomes. Drawing on survey data from Dutch construction firms, this study employs fuzzy-set qualitative comparative analysis (fsQCA) to investigate how six conditions, including Digital Product Passport (DPP) readiness, inter-organizational cooperation, business model innovation, government support, formal controls, and social controls, combine to achieve high CE performance. The findings reveal that DPPs are not stand-alone drivers but become strategically significant only when positioned within constellations of business model innovation, social controls, and cooperation. To conceptualize this role, the study introduces Material-Traceability-as-a-Service (MTaaS), a digitally-enabled service logic, through which DPPs evolve from static compliance tools into dynamic infrastructures for value-chain coordination. Five distinct, equifinal pathways to CE performance are uncovered, advancing causal-complexity theory in CE and digital servitization research, challenging linear, one-size-fits-all assumptions about circular transitions. This study contributes to theory by clarifying how digital infrastructures acquire value only through systemic alignment and by extending digital servitization with the MTaaS concept. For practice, it outlines strategic pathways that managers can tailor to organizational contexts, while offering policymakers direction on governance frameworks that enable and accelerate, rather than merely regulate, the transition toward a CE.

1. Introduction

Industries worldwide are increasingly adopting innovative strategies to advance sustainability by improving resource efficiency and reducing environmental impacts (Wang et al., 2024; Cainelli et al., 2020). Among them, the construction and built environment sector faces particular pressure due to its resource intensity and carbon footprint (Ebolor et al., 2022; Kinnunen et al., 2022). The Circular Economy (CE) has emerged as a leading paradigm for addressing these challenges and fostering sustainable growth (Kirchherr et al., 2017; Corona et al., 2019; Geissdoerfer et al., 2017; Ahmad et al., 2023). In contrast to the linear “take-make-dispose” model, CE seeks to design out waste and keep materials in circulation for as long as possible, thereby reducing virgin resource use and strengthening economic resilience (Eising-Mertsch et al., 2024; Vahidi, 2025; Yasmeen and Longsheng, 2025). Yet, despite its promise, the transition to circular models remains complex, requiring not only technological innovation but also changes in business models, partnerships, governance structures, and policymaking.

Against this backdrop, a growing body of evidence suggests that digital services and solutions can serve as powerful catalysts in enabling circularity (Vaezinejad et al., 2025; Bressanelli et al., 2024). Many sectors have used digital technologies to transition from product-oriented business models into more of a service and solution-oriented business model, the so-called digital servitization

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(Favoretto et al., 2022; Kowalkowski et al., 2017). This transformation has enabled a wide range of "as-a-service" business models to emerge, including Software-as-a-Service (SaaS) (Rodrigues et al., 2021), Platform-as-a-Service (PaaS) (Liu et al., 2024), and Product-as-a-Service (Hidalgo-Crespo et al., 2024), each reflecting a shift from static product ownership to continuous value delivery through data, usage, and service integration (Dalenogare et al., 2022). Such models are becoming increasingly relevant in sustainability transitions (Kolagar, 2024), as they support lifecycle thinking, asset reuse, and efficiency optimization. To enable this shift, firms are developing Digital Product Passports (DPPs) (King et al., 2023; Kebede et al., 2024). DPPs can be defined as digital records that track product-related information across the lifecycle, which have been promoted in EU policies as a way to support product transparency, traceability, and reuse (Wan and Jiang, 2025). While these systems are often seen as compliance mechanisms, emerging industry practices and academic work suggest that DPPs are evolving into something more strategic rather than just enabling documentation (Reich et al., 2023). That is, some firms are no longer treating DPPs as static documents but as technological innovations and infrastructural backbones that are part of a broader, dynamic model of value creation and coordination.

We conceptualize this emerging logic as "Material-Traceability-as-a-Service" (MTaaS), *"a digitally enabled service-based approach where traceability becomes an ongoing capability delivered across the value chain through technologies such as Artificial Intelligence (AI), blockchain, APIs, and real-time data platforms"*. Unlike traditional DPPs, which remain static records designed primarily for compliance, MTaaS reconfigures traceability into a continuous and adaptive service, one that generates ongoing value for multiple stakeholders across the product lifecycle. By integrating AI-driven analytics, MTaaS can transform raw traceability data into actionable insights for optimizing reuse, predicting material recovery potential, and supporting circular design and closed-loop material management decisions (Vaezinejad et al., 2025). MTaaS also differs from generic "as-a-service" models such as SaaS or PaaS: while these emphasize software delivery or computing infrastructure, MTaaS is explicitly designed to align with CE requirements by embedding traceability into material flows, enabling secondary markets, and fostering lifecycle decision-making. In this sense, MTaaS represents an extension of digital servitization (Dalenogare et al., 2022; Kolagar et al., 2022a) tailored specifically to the CE. It moves beyond one-time documentation and instead supports continuous engagement, lifecycle coordination, and cross-firm decision-making. Indeed, the concept of MTaaS draws inspiration from other service-based offerings but adapts the logic uniquely to the requirements of circularity.

While DPPs are often portrayed in policy and practice debates as stand-alone solutions to enable circularity, our study adopts a more critical stance (Zhang and Seuring, 2024). We argue that DPPs in isolation are unlikely to realize CE performance. Accordingly, this study does not examine DPPs as a dominant technological solution, but rather analyzes how their role is shaped and constrained by complementary organizational and institutional conditions. Indeed, their potential lies in how they are combined with other organizational and institutional enablers, evolving into MTaaS. This perspective moves beyond the prevailing hype by showing that DPPs only contribute to CE outcomes when embedded in specific configurations of business model innovation, cooperation, and governance mechanisms. In this way, our study acknowledges the strategic importance of DPPs while correcting overly simplistic assumptions of them as silver-bullet solutions.

Despite this potential, pathways to CE remain poorly understood, and firms are uncertain about how initiatives can best be effectively supported. In this regard, first, there is *a need to gain a deeper understanding of the diverse roles that DPPs may play in enabling CE, including, but not limited to,* their potential evolution to MTaaS. Prior studies have examined the importance of DPPs (Kebede et al., 2024; Wan and Jiang, 2025), Business Model Innovation (BMI) (Pollard et al., 2021; Pieroni et al., 2021), Inter-Organizational Cooperation (IOC) (Gonçalves and Franco, 2024), government support (Dagilienė et al., 2021; Wasserbaur et al., 2022), and formal and social controls (Rauter et al., 2023). Yet, limited attention has been given to how these seemingly distinct but interdependent conditions combine to enhance CE performance. This gap is especially relevant in the construction and built environment sector, where technical, institutional, and cultural heterogeneity is high (Ebolor et al., 2022). More broadly, emerging research on circular economy implementation and sustainability transitions suggests that CE outcomes are characterized by causal complexity, where performance emerges from the interaction of multiple technological, organizational, and institutional capabilities rather than from isolated drivers. This perspective implies that circular outcomes may arise from different combinations of enabling conditions rather than from a single dominant factor (Geissdoerfer et al., 2017; Eising-Mertsch et al., 2024; Rauter et al., 2023; Bocken et al., 2016). These studies highlight that similar circular outcomes can be achieved through different combinations of enabling conditions, depending on firm-specific and ecosystem-level contexts. Second, there remains a *lack of knowledge regarding effective strategy configurations that can lead to CE performance*. Evidence from digital servitization research shows that direct correlations between digital technologies and performance are rarely consistent across firms and contexts (Broccardo et al., 2023). This highlights the need for a configurational approach, which can move beyond linear explanations and reveal how circularity can be achieved through multiple, context-specific pathways. Through the configurational lens, three types of causal complexity can be captured (Ragin, 2008; Kolagar et al., 2024). It captures conjunctions (i.e., when different conditions act in conjunction rather than individually), equifinality (i.e., the desired result obtained by taking several paths), as well as causal asymmetry (in other words, low-performing configurations are not necessarily mirror images of high-performing configurations) (Kolagar et al., 2024). This approach provides a more accurate representation of how industrial firms pursue circularity through different equifinal configurations, compared with conventional linear and additive models. Accordingly, this study focuses on a theoretically grounded set of enabling conditions that capture complementary technological, organizational, inter-organizational, and institutional mechanisms shaping circular economy performance.

To fill these research gaps, this study aims to shed light on the complex relationships between six key factors (i.e., digital product passports, business model innovation, inter-organizational cooperation, government support, formal controls, and social controls), referred to as "conditions" in configurational analysis, which may combine in different ways to realize CE performance. Hence, the purpose of this study is to *"explore the different configurational strategies in order to realize CE performance for industrial firms"*. In this study, the term "industrial firms" is used as an umbrella concept to denote organizations operating in material-intensive sectors, with the empirical focus explicitly placed on firms in the construction and built environment sector. Also, the main research question of the study is *"what configurational strategies can industrial firms employ to achieve circular economy performance?"* In this study, CE performance refers to improvements in resource efficiency and environmental impact, including improvements in recycling, water reuse, energy use, and waste reduction. In doing so, we draw on a survey dataset of Dutch pioneer firms involved in the construction and built environment to identify different strategies that can lead to the realization of CE performance. By focusing on this sector as an important testbed for CE initiatives due to its high resource intensity and growing experimentation, we provide insights that address sector-specific challenges while also informing broader CE transitions. This study contributes to research on the implementation of the circular economy by linking digital servitization to CE performance and identifying multiple configurational strategies through which firms can realize circular outcomes. For practitioners and policymakers, the findings also underscore the importance of adopting a strategic, context-sensitive approach to CE, one that aligns technological and social capabilities through dynamic multi-condition strategies.

2. Theoretical background

2.1. Circular economy (CE) - from concept to performance

In today's competitive and ever-evolving marketplace, industrial firms face persistent challenges due to shifting consumer needs and intense competition (Kolagar et al., 2022b). Furthermore, organizations and societies also recognize that finite natural resources must be used more efficiently to safeguard future generations (Geissdoerfer et al., 2017; Ahmad et al., 2023). Despite its widespread uptake, the concept of CE is still not uniformly defined across disciplines or policy domains (Corona et al., 2019; Eising-Mertsch et al., 2024). Scholars and institutions have offered a variety of definitions that reflect distinct emphases, ranging from ecological regeneration, industrial symbiosis, and resource efficiency to BMI and socio-technical transitions. These differences reflect disciplinary lenses (e.g., engineering, environmental science, economics, management) and diverse stakeholder objectives (Geissdoerfer et al., 2017; Blomsma et al., 2019). Kirchherr et al. (2017) synthesized over 100 definitions and proposed a widely cited conceptualization of CE as “an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes … with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations” (Kirchherr et al., 2017). This foundational effort was significantly extended in a subsequent study by Kirchher et al. (2023), which systematically identified and analyzed 221 CE definitions across disciplines and stakeholder domains (Kirchherr et al., 2023). More recent scholarship has moved beyond definitional debates to focus on how CE principles are operationalized in real-world systems (Vaezinejad et al., 2025; Bauwens et al., 2024). This includes the development of circularity metrics (Brändström and Eriksson, 2022), integration into governance mechanisms (Becchetti et al., 2025), and alignment of resource flows with sustainability goals (Ahmad et al., 2023). These contributions collectively underline the need to shift from abstract definitions to actionable pathways. In this study, CE is not treated as a standalone theoretical framework. Rather, it serves as a normative and empirical domain within which configurational theory and digital servitization perspectives are applied to explain how circular economy performance emerges in practice. At its core, CE promotes strategies for resource retention and waste minimization by replacing traditional throughput logics with circular flows (Kirchherr et al., 2017). In the construction and built environment sector, a domain marked by high material consumption, waste generation, and carbon intensity, the relevance of CE principles is particularly acute (Vahidi, 2025). With long asset lifespans, fragmented supply chains, and resource-intensive operations, the move toward circularity offers both ecological and economic benefits (Ebolor et al., 2022; Kinnunen et al., 2022). CE performance denotes the tangible outcomes of “R-strategies” (Reduce, Reuse, Recycle, Repair, Refurbish, Remanufacture) (Zorpas, 2024), which are typically assessed using indicators such as reduction in virgin-material input, increased reuse/recycling, design-for-disassembly, and improved lifecycle efficiency (Eising-Mertsch et al., 2024; Yasmeen and Longsheng, 2025). However, achieving these outcomes requires a wide range of interrelated capabilities, and a configurational lens is needed to reveal multiple, equally effective pathways to CE success (Ahmad et al., 2023; Kolagar et al., 2024).

2.2. A configurational perspective on enabling circular economy performance

Much of the existing CE literature has focused on identifying barriers to implementation (Suresh et al., 2024; Hetherington et al., 2024). A growing body of work now emphasizes the importance of enabling conditions, including digital innovation, regulation, and business model changes, but these are often studied in isolation rather than in combination (Geissdoerfer et al., 2017; Ahmad et al., 2023; Eising-Mertsch et al., 2024; Vaezinejad et al., 2025; Wasserbaur et al., 2022; Mäkitie et al., 2023; Pieroni et al., 2019). Drawing on configurational theory and the broader causal complexity literature (Kolagar et al., 2024; Meyer et al., 2017), this study adopts a holistic perspective to investigate how multiple interdependent conditions jointly enable CE performance. Rather than treating antecedents in isolation, the configurational perspective focuses on how specific combinations of factors align to produce desired outcomes (Kolagar et al., 2024). Importantly, within a configurational logic, conditions are treated as analytically relevant sets rather than as variables of equal causal status; thus, technological mechanisms such as DPP readiness can be examined alongside organizational and institutional conditions without implying equivalence in their theoretical nature (Meyer et al., 2017; Schneider and Wagemann, 2012; Pappas and Woodside, 2021). Accordingly, the enabling conditions examined in this study were deliberately selected to capture complementary technological, organizational, inter-organizational, and institutional mechanisms that are repeatedly highlighted in prior CE, sustainability transition, and digital servitization research as central to the realization of circular outcomes, particularly in material-intensive sectors such as construction. Specifically, the selection of these enabling conditions is guided by three complementary considerations. First, prior research on the circular economy, sustainability transitions, and digital servitization consistently identifies these mechanisms as critical enablers of circular practices, yet they are often examined in isolation rather than jointly (Ahmad et al., 2023; Vaezinejad et al., 2025; Wasserbaur et al., 2022; Mäkitie et al., 2023). Second, together they capture multiple analytical levels central to the implementation of the circular economy, including enabling digital infrastructure (DPP readiness), organizational value logic (business model innovation), inter-organizational coordination (inter-organizational cooperation), institutional support (government support), and internal governance mechanisms (formal and social controls). Third, their selection reflects emerging policy and industry debates in the construction and built environment sector, where achieving circular outcomes depends on aligning digital traceability systems, innovation strategies, collaborative networks, and governance arrangements rather than on single-factor solutions (Kebede et al., 2024; Zhang and Seuring, 2024; Bauwens et al., 2024; Çetin et al., 2023). Building on this rationale, to operationalize this configurational perspective, we examine six enabling conditions that are grounded in both academic literature and emerging policy frameworks relevant to circular economy implementation: Digital Product Passport readiness, Business Model Innovation, Inter-Organizational Cooperation, Government Support, Formal Controls, and Social Controls. In line with configurational methodology, these elements are treated as enabling conditions, while the fsQCA analysis identifies configurations, defined as empirically observed combinations of conditions that jointly lead to the outcome of circular economy performance. This approach reflects the core premise of configurational analysis, which does not seek to identify isolated causal effects but instead explains how different enabling mechanisms combine to produce multiple pathways toward circular economy performance (Meyer et al., 2017; Schneider and Wagemann, 2012; Pappas and Woodside, 2021; Wei et al., 2022). The following subsections define each enabling condition, anchor it in the relevant literature, and present propositions regarding its potential role in shaping circular economy performance when combined with other complementary conditions. Moreover, Fig. 1 illustrates the proposed theoretical framework.

2.2.1. Digital Product Passport (DPP) readiness

DPPs are becoming core infrastructures for CE transitions in material-intensive sectors such as construction, manufacturing, and electronics (Vahidi et al., 2024). Anchored in the EU's Circular Economy Action Plan (European Commission, 2020), digital passports function as

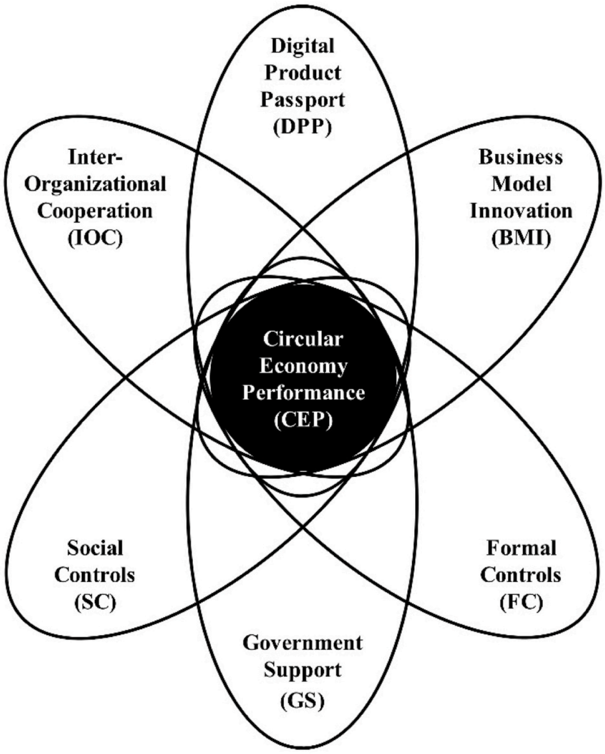

Fig. 1. Theoretical model of the research.

digital records that store lifecycle data on composition, origin, durability, repairability, and environmental impact, which can enable traceability and informed choices from design to end-of-life (King et al., 2023; Kebede et al., 2024; Wan and Jiang, 2025). Similarly, DPP readiness reflects a firm's ability to combine digital infrastructure (IoT, blockchain, BIM) with strong data stewardship (King et al., 2023; Kebede et al., 2024; Wan and Jiang, 2025; Zhang and Seuring, 2024). Recent debates have increasingly portrayed DPPs as a foundation for implementing CE principles. At the same time, scholarship suggests that their impact depends on how they are designed and integrated into broader organizational practices. Importantly, we conceptualize an emerging extension of this readiness as "Material-Traceability-as-a-Service" (MTaaS), a digitally enabled service logic in which traceability becomes a continuous value offering rather than a one-time documentation function. AI-driven analytics can further enhance this logic by enabling predictive maintenance, automated data verification, and real-time insights into material reuse and recovery potential, thereby reinforcing DPPs as intelligent components of circular value chains (Vaezinejad et al., 2025; Mäkitie et al., 2023). Unlike conventional tracking tools, MTaaS leverages DPP infrastructure to deliver ongoing lifecycle intelligence and decision support across the ecosystem, aligning with digital servitization principles and circular value co-creation (Kolagar, 2024; Dalenogare et al., 2023). Examples of early applications include Madaster, a Dutch platform that tracks and valorizes building components, and the BAMB project, which links material passports to BIM for reversible design and secondary-material markets (Kebede et al., 2024; Çetin et al., 2023; Vahidi et al., 2024; Heisel et al., 2020). Despite successes, challenges remain in standardization, data interoperability, and system integration, especially in fragmented sectors. Therefore, DPP readiness and the ability to implement MTaaS may affect how firms approach CE practices, indicating not only technological maturity but also a strategic orientation toward continuous CE performance. In this study, DPP readiness is therefore conceptualized not as an independent driver of circular outcomes but as an enabling digital mechanism whose contribution depends on how it is embedded within organizational practices, governance arrangements, and inter-organizational structures. From a configurational perspective, the contribution of DPP readiness does not emerge in isolation but depends on how digital traceability capabilities interact with complementary organizational and institutional mechanisms within the broader circular ecosystem. Taking these arguments into account, we develop the following proposition:

Proposition 1. *DPP readiness is a condition that can enhance CE performance when aligned with complementary organizational and institutional enabling conditions.*

2.2.2. *Business Model Innovation (BMI)*

BMI realigns how firms create, deliver, and capture value in response to environmental and technological change (Foss and Saebi, 2018; Latifi et al., 2021). In CE, BMI decouples growth from resource use by shifting from ownership to hybrid or service logics, product-as-a-service, take-back schemes, and modular upgrades (Pollard et al., 2021; Pieroni et al., 2019). This approach allows industrial firms to extend lifecycles, retain materials in use, and pursue scalable sustainability-led growth (Colovic, 2022). Conversely, without suitable business model configurations, even technologically advanced or well-managed firms may fail to achieve circular outcomes. In this study, BMI is conceptualized broadly as changes in value creation, value delivery, and value capture logics (Foss and Saebi, 2018; Latifi et al., 2021) that enable firms to retain materials in use, extend product lifecycles, and align economic value creation with circular resource flows, rather than as isolated business model practices or sector-specific solutions. From a configurational perspective, BMI is therefore not expected to operate as a standalone driver of circular outcomes but rather as a complementary organizational mechanism whose contribution emerges through its alignment with other enabling technological, institutional, and governance conditions. Accordingly, we present the following proposition:

Proposition 2. *BMI is a condition that can contribute to CE performance when configured with other enabling conditions.*

2.2.3. *Inter-organizational cooperation (IOC)*

Achieving CE requires shared innovation, resource pooling, and strategic alignment (Kusa et al., 2023). Such cooperation enhances environmental outcomes and competitive advantage, particularly through ecological partnerships with customers and suppliers (Kolagar, 2024). In the construction and built environment sector, cooperative strategies have been linked to improvements in circular practices such as material reuse, digital coordination, and life cycle planning (Ebolor et al., 2022; Kinnunen et al., 2022). Within a configurational framework, inter-organizational cooperation becomes particularly relevant when it complements other enabling mechanisms, such as digital infrastructures, supportive institutional environments, and internal governance arrangements that collectively facilitate circular practices. We therefore present the following proposition:

Proposition 3. *IOC is a condition that can support CE performance as part of broader constellations of enabling conditions.*

2.2.4. *Government support (GS)*

Government support is important for firms pursuing sustainability transitions (Wasserbaur et al., 2022). In CE and Industry 4.0 contexts, policy and institutional backing reduce uncertainty, provide incentives, and establish regulatory rules (Dagilienė et al., 2021). Evidence shows that such support boosts innovation, sales, and market reach, especially for smart manufacturing and traceability technologies (Jang et al., 2023). Although research on circular traceability is still limited, studies suggest that subsidies, funding, and targeted laws accelerate the diffusion of CE and digital infrastructures (Luthra et al., 2020; Verma et al., 2022). From a configurational perspective, government support therefore functions as an institutional condition that can reinforce or amplify the effectiveness of technological and organizational initiatives aimed at advancing circular economy performance. Therefore, we propose the following proposition:

Proposition 4. *Government support is a condition that can strengthen CE performance when embedded within a broader set of enabling conditions.*

2.2.5. Formal controls (FC)

Formal controls translate CE ambitions into operational targets by specifying expected outputs and required behaviors, reducing ambiguity, and improving organizational coordination (Rauter et al., 2023). In CE innovation, these mechanisms can turn broad sustainability aims into priorities and decision rules (Yasmeen and Longsheng, 2025). By reducing information asymmetry, enhancing communication, and motivating competence development, FC empowers employees to pursue circular goals. Tools such as CE-specific KPIs, audits, performance reviews, and certification link sustainability objectives to innovation activities (Bauwens et al., 2024). Without such structures, sustainability considerations may be inconsistently interpreted, whereas robust controls provide the clarity, accountability, and resource alignment critical for scaling CE innovations (Rauter et al., 2023). Within a configurational logic, formal controls are most effective when they operate alongside complementary organizational and institutional conditions that collectively guide the implementation of circular strategies. Based on these arguments, we propose the following proposition:

Proposition 5. *FC is a condition that can facilitate CE performance when combined with other organizational and institutional enabling conditions.*

2.2.6. Social controls (SC)

Beyond structural mechanisms, such as formal controls, organizational culture plays a significant role in shaping how sustainability objectives, including those aligned with the CE, are enacted across different levels of a firm. Social controls refer to the shared norms, values, and visions that guide individual behavior toward collective goals (Rauter et al., 2023). Operating through trust, peer influence, and leadership commitment, these controls align decisions with firm priorities (Kirsch et al., 2009). They are especially relevant in CE contexts where innovation tasks are complex, unstructured, and challenging to monitor or quantify. Both hierarchical (leaders signaling commitment) and lateral (peers reinforcing CE values) (Rauter et al., 2023) forms of social control promote proactive information sharing, sustainability-oriented decision-making, and a sense of shared accountability. From a configurational standpoint, social controls can strengthen the effectiveness of other enabling conditions by fostering shared commitment, coordination, and collective orientation toward circular objectives across the organization. Therefore, we propose the following proposition:

Proposition 6. *SC is a condition that can promote CE performance when combined with other enabling conditions.*

3. Methodology

3.1. Sample and data collection

As part of our study, we examined the different configurations of “digital product passport”, “inter-organizational cooperation”, “business model innovation”, “government support factor”, “formal controls”, and “social controls” conditions that can lead to a higher circular economy performance in a sample of 200 firms involved in the Dutch construction and built environment ecosystem. Given the novelty and futuristic nature of this topic, a thorough industry-wide investigation has been undertaken to identify the companies that are most relevant to leveraging traceability solutions for the circular economy in the Netherlands. In doing so, several criteria have been considered in selecting a company to participate in our data collection process, including their involvement in the construction and built environment ecosystem, their use of digital technologies for managing their business operations, and their reputation as pioneers in sustainability and circularity initiatives. The preliminary version of the developed questionnaire was reviewed for content validity by managers from firms of differing sizes. We then emailed each CEO or general manager a cover letter with a survey link, followed by two reminders and a telephone follow-up. The process produced 46 responses, 43 of which were complete and suitable for analysis. Three academic researchers and two industry managers pilot-tested the questionnaire to ensure item clarity and dimensional alignment. All constructs were measured using multi-item scales adapted from validated prior studies, except for DPP readiness, which was newly developed for this research. An iterative researcher-practitioner review and a pilot survey were carried out to validate the reliability and validity of this new scale, which assesses planned investments and readiness in implementing technologies such as blockchain platforms, APIs, and BIM. The other constructs, including inter-organizational cooperation, business model innovation, government support, formal controls, social controls, and CE performance, were adapted from established literature (Rauter et al., 2023; Latifi et al., 2021; Kusa et al., 2023; Jang et al., 2023; Sahoo and Jakhar, 2024). All multi-item measures were rated on seven-point Likert scales ranging from “strongly disagree” (1) to “strongly agree” (7).

We verified construct validity and reliability with congeneric measurement techniques, which provide more accurate estimates of latent constructs in configurational research (Kolagar et al., 2024; Balzano and Marzi, 2023). Using the CLC estimator tool, we calculated factor loadings, Cronbach's alpha, and average variance extracted (AVE) for each scale (Marzi et al., 2023). As summarized in Table I, all constructs exceeded the recommended thresholds for Cronbach's alpha (0.70) and AVE (0.50), confirming internal consistency and convergent validity (Kolagar et al., 2024). The detailed item loadings, all of which exceed the acceptable threshold of 0.60, are reported in Appendix A and further support the validity of the measures. Together, these analyses confirm that the measurement instruments demonstrate satisfactory reliability and validity for use in fsQCA analysis.

3.2. Data analysis using fuzzy-set qualitative comparative analysis

The fuzzy-set qualitative comparative analysis (fsQCA) approach is employed in this research to explore the propositions of the study, combining fuzzy set theory and fuzzy logic with qualitative comparative analysis (QCA) (Kolagar et al., 2024; Balzano and Marzi, 2023). While it is becoming increasingly popular in management and sustainability research (Kolagar et al., 2024), fsQCA remains a relatively novel approach within the circular economy (CE) literature, offering new opportunities to explore how multiple conditions interact to enhance circularity. With this approach, qualitative depth and quantitative reach can be achieved simultaneously, avoiding the net-effect limits of structural equation models and incorporating exploratory and hypothesis-testing insights as requirements. Instead of estimating single linear coefficients, this technique traces configurations of conditions that together yield an outcome, generating set-membership propositions rather than traditional hypotheses (Balzano and Marzi, 2023). As a result of this approach, patterns of elements (i.e., configurations) can be identified between both the independent and dependent variables, and

Table 1
Constructs and their reliability and validity information.

Constructs	No. of items	Cronbach's alpha	AVE
Digital Product Passport (DPP)	10	0.88	0.59
Inter-Organizational Cooperation (IOC)	4	0.86	0.64
Business Model Innovation (BMI)	6	0.83	0.62
Government Support Factor (GSF)	5	0.84	0.66
Formal Controls (FC)	5	0.90	0.67
Social Controls (SC)	5	0.88	0.61
Circular Economy Performance (CEP)	5	0.81	0.68

the analysis extends beyond variance and multiple regression analyses. It also distinguishes necessary from sufficient conditions and recognizes that more than one pathway can produce the same result (equifinality). In this configurational lens, causal asymmetry is captured, success and failure are not necessarily mirror images, and the limited diversity that occurs in real datasets is accepted (Ragin, 2008; Kolagar et al., 2024). In this study, we interpret the configurations identified through fsQCA as empirically grounded strategic pathways. Importantly, these strategies are not meant to suggest that firms consciously or deliberately choose among them in a prescriptive sense. Rather, the method uncovers recurring patterns of conditions across firms that can be interpreted as feasible routes toward CE performance. This clarification ensures that readers understand our use of the term “strategic choice” as an analytical lens rather than as evidence of deliberate decision-making sequences by individual firms. Through its triangulation of qualitative richness with set-theoretic rigor, fsQCA offers nuanced insights into how digital, structural, institutional, and cultural factors interact in the rapidly evolving circular economy.

4. Results and discussion

4.1. Necessity analysis

Necessity and sufficiency analyses form the foundation of configurational path analysis by identifying whether core antecedent conditions exist (Kolagar et al., 2024). A condition is necessary when it consistently appears with the outcome. Consistency reflects how reliably it leads to the outcome, and coverage shows how much of the outcome is explained by the condition (Wei et al., 2022). According to Ragin (2008) and Schneider and Wagemann (2012), a condition is considered necessary when its consistency score exceeds 0.9, accompanied by coverage scores greater than 0.8 (Ragin, 2008; Schneider and Wagemann, 2012). In fsQCA, however, values below these thresholds do not indicate analytical weakness. Instead, they confirm that no single condition qualifies as universally necessary for the outcome, which aligns with the configurational logic of causal complexity (Ragin, 2008; Pappas and Woodside, 2021). Table II presents the consistency and coverage of all conditions regarding the presence and absence of CE performance.

The necessity of each condition's presence or absence was tested. By taking DPP readiness as an example, we will provide a more detailed description of the process. According to the analysis, DPP leads to a moderate consistency of 68% in terms of high CE performance when digital traceability solutions are used. As a result, DPP contributes to the presence of the outcome to a considerable extent. Furthermore, DPP covers 72% of the cases in which high CE performance is observed. This suggests that DPP explains a substantial proportion of the present cases of the outcome. In the absence of DPP, there is moderate consistency of 60% in the absence of high CE performance. This indicates that the absence of DPP contributes to the absence of the outcome to some extent. Furthermore, DPP covers 65% of the cases where high CE performance is not achieved. According to this, although the absence of DPP contributes to the absence of the outcome, it is not the sole determinant responsible for it. In this regard, no single condition fully explains the high level of CE performance, as the consistency and coverage values of all conditions for CE performance are lower than the thresholds. This finding reinforces our conceptual position that DPPs cannot be treated as universal or sufficient drivers of CE performance. Instead, they matter significantly only in combination with other conditions, which justifies moving towards a configurational analysis. It also supports all six propositions: firms in the construction and built environment can achieve high CE performance under different configurations of DPP, inter-organizational cooperation, BMI, government support, formal controls, and social controls. Moreover, the absence analysis indicates that none of the conditions in isolation fully account for the absence of high CE performance, emphasizing the necessity for synergistic combinations of conditions to achieve the desired outcome. These results justify further path analysis to explore the specific high-performing configurations.

Table 2
Analysis of necessary conditions.

Conditions Tested	Presence		Absence	
	Consistency	Coverage	Consistency	Coverage
DPP	0.68	0.72	0.63	0.58
~DPP	0.60	0.65	0.69	0.66
IOC	0.68	0.67	0.72	0.63
~IOC	0.62	0.72	0.62	0.63
BMI	0.71	0.70	0.67	0.58
~BMI	0.57	0.66	0.65	0.66
GSF	0.65	0.75	0.58	0.59
~GSF	0.64	0.63	0.76	0.66
FC	0.79	0.71	0.62	0.49
~FC	0.44	0.57	0.64	0.73
SC	0.76	0.75	0.52	0.46
~SC	0.45	0.52	0.72	0.72

Note: DPP = Digital Product Passport, IOC = Inter Organizational Cooperation, BMI = Business Model Innovation, GSF = Government Support Factor, FC = Formal Controls, SC = Social Control; “~” indicates the negation of the condition.

4.2. Sufficiency analysis

A sufficiency analysis was conducted to determine whether the cases displaying the conditions constitute a subset of those displaying the outcome. Indeed, sufficiency refers to the explanatory strength of the condition in explaining the occurrence of the outcome (Sjödin et al., 2019). Using a truth table (Balzano and Marzi, 2023), we derived configurations that account for superior CE performance. As shown in Table III, the overall consistency is 0.86, and each path configuration exceeds 0.87, which is above the recommended threshold of 0.80 (Ragin, 2008). Furthermore, the overall coverage of 0.63 confirms that these combinations of causal conditions account for 63% of cases.

As part of this section, we will discuss five configurations that result in high CE performance in construction and built environment companies. Each configurational strategy (CS) reflects a distinct combination of conditions. Core conditions (marked in both parsimonious and intermediate solutions) are central to success, while peripheral

Table 3
Configurations for high circular economy performance.

Configurations	I	II	III	IV	V
Digital Product Passport	●	•	•		○
Inter-Organizational Cooperation	•	•		•	○
Business Model Innovation	•	●	•	•	○
Government Support Factor	•		•	•	○
Formal Controls		•	•	•	•
Social Controls	●	●	•	•	•
Raw Coverage	0.42	0.49	0.44	0.46	0.29
Unique Coverage	0.01	0.05	0.02	0.04	0.05
Consistency	0.89	0.87	0.88	0.89	0.87
Solution Coverage	0.63				
Solution Consistency	0.86				

Note: As per the notation of Fiss (2011), the solutions are grouped by their core structures: black circles indicate the presence of the condition; white circles indicate the absence of the condition; blank spaces indicate that the condition may be present or absent (i.e., it is irrelevant).

conditions (present only in intermediate solutions) provide supporting roles. CS-I features DPP readiness and social controls as core, supported by inter-organizational cooperation, BMI, and government support. It reflects a digital traceability-driven strategy grounded in infrastructure and sustainability culture. This configuration demonstrates that DPPs can contribute meaningfully to CE performance, but only when accompanied by supporting conditions such as BMI, collaboration, and cultural alignment. In this sense, DPPs operate as catalysts within broader configurations rather than as independent levers of change. CS-II is the most supported configuration. BMI and social controls are core, with DPP readiness, cooperation, and FC as peripheral. It combines value innovation with internal alignment, even without government support. CS-III includes FC, DPP readiness, BMI, government support, and social controls as peripheral conditions, with no core condition. It reflects performance driven by internal systems and policy alignment, not collaboration. CS-IV includes no core condition, and DPP is irrelevant. CE outcomes stem from cooperation, BMI, government support, and controls, illustrating a non-digital, distributed logic. And finally, CS-V is minimalistic: only formal and social controls are present, supporting CE through internal governance, particularly in smaller or compliance-oriented firms. The combination of these configurations confirms causal asymmetry and equifinality, and the possibility of achieving CE performance through a variety of factors, including core and supporting ones.

4.3. Configurational strategies for achieving high circular economy performance

This study identified five distinct configurations, or equifinal pathways, that can lead to a high level of CE performance among companies in the Dutch construction and built environment sector. The findings of this study confirm that multiple paths can be taken to achieve the desired outcome, such as waste minimization, material reuse, and resource efficiency. Each pathway reflects a distinct alignment of organizational capabilities, governance mechanisms, and external enabling conditions that together support the realization of circular economy performance. It is essential to clarify that these strategies should be understood as patterns emerging from comparative analysis rather than as deliberate choices made by managers in a stepwise fashion. Firms may not explicitly recognize themselves as following a given pathway, but their practices and conditions align in ways that allow us to interpret the outcome as the realization of a particular

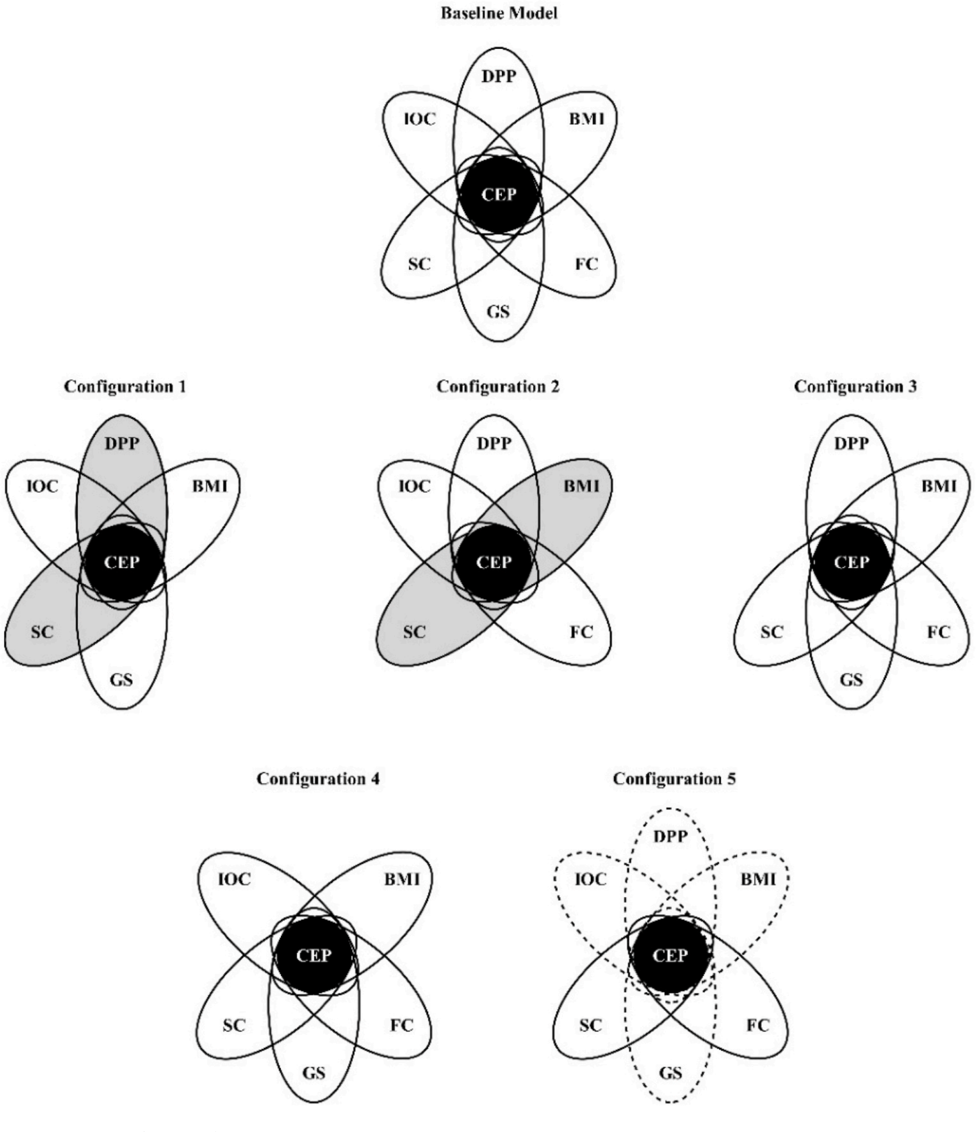

Fig. 2. Configurational strategies toward CE performance
Note: Bold lines indicate the presence of a condition, dashed lines indicate its absence. Solid-filled circles indicate the presence of a core condition; dashed-filled circles indicate the absence of a core condition. Absence of circles indicates "do not care" condition.

strategic configuration. Here, each configuration is further elaborated through conceptual interpretation and illustrative real-world analogues from the Dutch construction and built environment sector. These illustrations are intended to demonstrate how the enabling mechanisms identified in the configurational analysis manifest in practice, rather than to provide full case-study narratives. The five resulting configurations reflect distinct strategic logics through which firms realize CE performance: some are digitally driven and innovation-oriented, while others rely on non-digital cooperation or compliance-based governance. The illustrative examples that follow demonstrate how these strategic logics materialize in concrete organizational and project contexts within the Dutch construction ecosystem. These empirical illustrations demonstrate how the enabling mechanisms identified in the configurational analysis manifest in practice and should therefore be interpreted as examples of broader configurational patterns rather than as exhaustive representations of the conditions themselves. In other words, the examples provided serve to illustrate how the enabling conditions identified in the configurational analysis materialize in specific empirical contexts, without restricting the broader conceptual scope of constructs such as business model innovation, inter-organizational cooperation, or governance mechanisms. Fig. 2 illustrates the different configurations that resulted from the analysis.

The *first configurational strategy* (CS-I) is characterized by the central role of DPPs and strong internal social controls, supported by inter-organizational collaboration, BMI, and moderate government engagement. It represents an archetype wherein CE performance is achieved through organizational foresight, digital infrastructure, and embedded sustainability values, rather than top-down regulatory enforcement. In the Dutch construction sector, frontrunner firms have increasingly viewed DPPs not only as an anticipated regulatory requirement but also as a strategic capability to enhance traceability, transparency, and circular material flows (Zhang and Seuring, 2024; Çetin et al., 2023). For example, Madaster Foundation has created a national built-environment material passport platform that facilitates the registration and documentation of the material composition, origin, and potential future re-use of all components used in buildings and other long-lived infrastructure assets (Heisel et al., 2020). It was found that buildings registered on this platform demonstrate an increase of 30% in material circularity potential compared to non-registered buildings (Heisel et al., 2020), primarily due to enhanced design-for-disassembly practices and materials selected based on their recyclability and reuse potential. Moreover, the system can assist asset managers and developers in calculating residual material value, which affects financial decisions and insurance premiums. Several Dutch municipal and public-private circular projects, such as those in Amsterdam and The Hague, use this platform to track and plan the performance of the circular economy. Similarly, organizations such as Cirkelstad and Alba Concepts have supported digital traceability systems in circular construction projects by combining Building Information Modeling (BIM) and material passport systems.

Material-Traceability-as-a-Service is a digitally driven servitization model that captures this logic by showing that DPPs alone are insufficient, but when configured with supporting conditions, they enable ongoing, real-time information exchange throughout the value chain (Vahidi et al., 2024). Importantly, these examples should be interpreted as illustrative manifestations of the broader enabling mechanisms identified in the configurational analysis, rather than as exhaustive representations of the underlying constructs such as business model innovation or digital servitization. AI-enhanced MTaaS solutions can further strengthen this configuration by transforming passive traceability data from building components and materials into predictive insights that inform design-for-disassembly, renovation planning, and closed-loop construction resource management (Vaezinejad et al., 2025; Mäkitie et al., 2023). Throughout this strategy, social control is also expressed through leadership involvement, clearly defined sustainability KPIs, and consistent internal communication, which integrate circular practices into the daily operations of the organization (Gieβ and Möller, 2025). Additional support comes from peripheral enablers such as partnerships with architects and deconstruction specialists, as well as the adoption of service-based innovations like façade leasing (Azcárate-Aguerre et al., 2023). Although government support is helpful, it is not the main driving force; the firms set the policy benchmarks.

The *second configurational strategy* (CS-II) centers on BMI and social controls as core enablers, supported by moderate DPP readiness, inter-organizational cooperation, and formal controls. It exemplifies entrepreneurial value creation in firms with strong sustainability cultures. A concrete example of this type of configuration can be seen in the modular-housing providers running housing-as-a-service schemes in Groningen and at the Green Village living lab at TU Delft. By partnering with stakeholders, firms such as Dura Vermeer lease prefabricated, demountable units instead of selling them, extending their lifecycles and reducing their raw-material costs (OECD, 2024; The Green Village, 2020). Leasing retains ownership for end-of-life recovery and aligns with the Dutch Circular Construction Economy 2023–2030 agenda (Rijksoverheid, 2023). In this strategy, DPPs aid component tracking and maintenance scheduling, but are not critical to business success. Additionally, companies can co-create circular solutions with suppliers, municipalities, and manufacturers of modular systems; platforms like Superuse Studios can repurpose urban waste streams into new buildings. Additionally, formal controls reinforce performance via reporting and audits, yet cultural embedding and BMI remain the primary drivers of circular value creation.

The *third configurational strategy* (CS-III) features no core condition but relies on a combination of formal controls, BMI, social controls, government support, and DPP readiness as peripheral enablers. This reflects a compliance-oriented strategy in which multiple mechanisms collectively drive CE performance. A fitting example is public infrastructure contractors engaged in Rijkswaterstaat projects like the A27 renovation and Zuidasdok. These projects apply the MilieuPrestatie Gebouwen (MPG) standard, requiring data on material use, emissions, and reuse potential. Rijkswaterstaat's circular procurement guidelines (2020) further demand evidence of reduced virgin material usage and increased reuse. Some initiatives also test the CB’23 circular metrics framework to align procurement with CE objectives (Çetin et al., 2023). This incentivizes practices such as using recycled asphalt, demountable concrete, and low-carbon materials. In this setting, CE performance stems from compliance with procurement guidelines, environmental KPIs, and reporting protocols. Firms adopt structured responses, such as reused materials and DPPs when needed, while BMI remains moderate (e.g., resale of deconstructed concrete) and is supported by formal KPIs and sustainability roles (Jonker-Hoffrén, 2023). Social controls can also be implemented through ISO 14001 certification and internal sustainability communication, but none of these mechanisms dominate, underscoring a diffuse but effective governance logic.

The *fourth configurational strategy* (CS-IV) outlines a distinct non-digital pathway to CE performance, driven by inter-organizational cooperation, BMI, and both formal and social controls, while DPP readiness is irrelevant. This approach demonstrates how circular flows and material recovery can be effectively managed through logistics, coordination, and shared governance, without reliance on digital infrastructure. A key example is Het Nieuwe Normaal (The New Normal), a collaborative initiative led by Platform CB’23 and the Dutch Green Building Council, which provides national guidelines and tools for assessing circularity in construction. Pilot projects under this framework have achieved up to 60% reuse of building materials, significantly reducing environmental impacts (Het Nieuwe and Normaal, 2023). Participating developers established urban depots at Utrecht to redistribute materials such as insulation panels and bricks across multiple sites, supported by municipal incentives such as expedited permit approvals and competitive tenders (Cramer, 2024). Rather than relying on digital systems, firms in this configuration rely on trust-based relationships, shared goals, and internal policies to enable reuse. Moreover, BMI manifests its presence through service contracts related to the pooling and logistics of materials. This strategy reflects institutional field-level coordination, demonstrating that digital maturity, on its own, does not guarantee high CE performance.

The *fifth and final configurational strategy* (CS-V) demonstrates that high CE performance can be achieved through a compliance-driven internal strategy, defined by strong formal and social controls, with other conditions (DPPs, collaboration, government support, innovation) playing no significant role. This reflects a governance model rooted in internal rules and shared values rather than systemic transformation. A representative case is Van Wijnen, a contractor engaged in sustainable housing projects like the NOM (Zero-on-the-Meter) program. In initiatives such as 'De Loskade' in Groningen, the firm employs modular design and adheres to internal BREEAM-NL and MPG protocols to enhance energy efficiency and material reuse (Van Wijnen et al., 2022). These projects report up to 80% on-site material separation and 40% lower energy consumption per unit than standard builds. Consequently, sustainability is institutionalized by internal KPI, staff training, audits, and alignment with sector-level environmental regulations (Wouterszoon et al., 2023). Social controls also stem from leadership engagement and cultural alignment, while formal mechanisms include mandatory reviews and audits. Although less transformative, this configuration is highly effective for firms that operate in stable, regulation-driven environments.

Thus, these five configurational strategies illustrate how firms can achieve CE performance through distinct yet equifinal strategic pathways. A cross-case comparison further reveals that these strategies differ not only in their digital intensity but also in their underlying governance logic. CS-I and CS-II represent innovation-driven digital pathways, where DPP readiness interacts with business model innovation and social alignment to enable proactive circular transformation. By contrast, CS-III and CS-V reflect compliance-oriented strategies, where circular outcomes primarily emerge through formal and cultural controls, whereas CE outcomes are achieved through structured governance and adherence to policy standards. CS-IV, meanwhile, demonstrates a non-digital cooperative model rooted in trust-based coordination and resource pooling. This comparative synthesis highlights that circular transformation is not monolithic but rather contingent upon how digital, organizational, and institutional enabling conditions interact within specific contexts to produce distinct configurational pathways toward circular economy performance. Notably, DPP readiness is evident in three of the five high-performing configurations, underscoring its growing strategic relevance across diverse CE strategies. However, its presence alone is not sufficient to generate circular outcomes; it must be complemented by business model innovation, social alignment, and inter-organizational collaboration. Of particular significance is the emergence of MTaaS as a novel concept, evident in the first configuration, where DPPs evolve from static compliance tools into value-creating digital services. This pathway offers a clear link between digital servitization and CE performance, one that is highly relevant as DPPs become formalized across EU sectors. Overall, the findings demonstrate that while digital traceability is a recurring feature of high-performing configurations, it delivers impact only when embedded within supportive models of innovation, cooperation, and governance. Taken together, these results reinforce the central premise of configurational theory: that circular economy performance does not arise from single drivers but from specific combinations of technological, organizational, and institutional enabling conditions.

5. Conclusions and implications

This study provides several key insights into how circular economy (CE) performance emerges in complex industrial settings. First, the results demonstrate that CE performance does not follow a single dominant pathway but can be achieved through multiple equifinal configurations of technological, organizational, and institutional conditions. Second, the findings reveal that digital traceability mechanisms such as Digital Product Passports (DPPs) contribute to circular outcomes only when embedded within complementary arrangements, particularly business model innovation and governance mechanisms that coordinate actors and incentives across the value chain. Third, the analysis shows that different governance logics, including innovation-driven, cooperation-oriented, and compliance-based configurations, can all support CE performance when enabling conditions align appropriately. Together, these insights highlight that circular transformation is not driven by isolated tools or policies but by the systemic alignment of digital infrastructures, organizational strategies, and institutional support mechanisms.

5.1. *Theoretical contributions*

This study contributes to the Circular Economy (CE) (Kirchherr et al., 2017; Corona et al., 2019; Eising-Mertsch et al., 2024) and digital servitization (Favoretto et al., 2022; Kowalkowski et al., 2017; Kolagar et al., 2022a) research by advancing a configurational perspective on how CE performance is realized in practice through the interaction of technological, organizational, and institutional conditions. First, it advances theory on how CE performance emerges from complex interdependencies. Past work has isolated drivers such as digital readiness, government incentives, or business model shifts; our fsQCA results show that no single factor is sufficient. By capturing causal complexity, conjunctural causation, and equifinality, we answer recent calls for systemic, multi-causal views of circular value creation.

Second, we introduce Material-Traceability-as-a-Service (MTaaS) as an extension of digital servitization. Although Digital Product Passports (DPPs) now feature prominently in EU policy, most studies still frame them as compliance tools. Our study repositions DPPs as infrastructural elements that gain practical and theoretical relevance only when embedded in complementary arrangements and service-oriented solutions that enable real-time traceability, multi-actor coordination, and lifecycle value creation. Rather than assuming a deterministic role, we show that their contribution emerges when they are mobilized through business models, inter-organizational coordination, and governance mechanisms. This insight shifts the debate from seeing DPPs as predefined solutions toward recognizing them as enablers that require systemic alignment for creating, delivering, and capturing environmental value (Kolagar, 2024; Mäkitie et al., 2023).

Third, we identify five distinct strategic pathways to high CE performance. Three include the DPP condition, yet the strongest configuration combines DPP readiness with BMI and social controls, showing that digital traceability is valuable but insufficient unless embedded in supportive models and cultures. This reinforces the view that the circular economy cannot be advanced through singular technologies or isolated managerial practices, but rather through constellations of conditions where tools such as DPPs are integrated into broader transformation strategies. Overall, the results deepen causal-complexity research in sustainable transitions by clarifying how digital and organizational enablers co-evolve in CE.

5.2. *Managerial and policy implications*

This study also holds important implications for industry practitioners, technology providers, and policymakers working to accelerate CE transitions in industrial sectors. First, managers should recognize that CE performance is not achieved through isolated initiatives or technologies, but through coherent combinations of strategic and organizational conditions. The identification of multiple equifinal pathways suggests that firms should adopt tailored, context-sensitive strategies that align with their current capabilities and stakeholder ecosystems. For example, organizations with strong digital capabilities but weak governance structures may not achieve circular outcomes unless supported by formal and social controls that align internal activities with sustainability goals (Rauter et al., 2023).

Second, the results highlight the importance of BMI and social controls as foundational enablers of circular value creation. Practitioners should move beyond compliance-driven approaches and instead embed circularity into their value propositions, delivery systems, and capture mechanisms (Bocken et al., 2016), but such embedding will only be visible if supported by a solid business case and clear market demand. As part of this endeavor, cultivating shared norms and values through leadership engagement, training, and cross-functional collaboration highlights the importance of prioritizing these initiatives. The five strategies identified in this study should not be interpreted as prescriptive formulas that firms consciously select from. Instead, they represent empirically observed pathways that organizations in the Dutch construction and built environment sector have followed to achieve CE outcomes. Managers can use these strategies as diagnostic tools: by comparing their own organizational profile against these patterns, they can identify which enabling conditions are currently strong and which may need reinforcement. In this way, the configurational strategies provide guidance for shaping interventions without implying that firms must deliberately “choose” one pathway over another.

Third, DPP and MTaaS models are emerging as vital infrastructures for circular transitions. As three out of five high-performing configurations in our analysis featured the DPP condition, it is becoming evident that digital traceability is not just a niche tool but a growing strategic imperative. Managers should view DPPs as platforms that must be connected with organizational routines and value propositions, rather than as stand-alone digital repositories. Indeed, they should not only invest in digital platforms and data governance but also develop the capabilities to integrate DPPs into everyday workflows, from procurement to design, use, and end-of-life management. Similarly, policymakers must design regulatory frameworks and standards that not only mandate DPPs but also incentivize their integration with innovation practices, cooperation platforms, and governance systems. The lack of such integration risks reducing DPPs to static compliance instruments with limited transformative potential.

For policymakers, this study underscores the need to design systemic interventions rather than isolated regulations. They must develop regulatory frameworks and standards that not only mandate DPPs but also incentivize their integration with innovation practices, cooperation platforms, and governance systems. The orchestration of institutional, organizational, and technological support is critical. Governments should couple regulatory incentives (e.g., tax credits, procurement policies) with investments in digital infrastructure and inter-organizational platforms that can host and scale MTaaS offerings. As recent scholarship suggests (Hartley et al., 2023), CE policies are most effective when delivered as coordinated policy mixes that span product lifecycles and include measures such as procurement, eco-design guidelines, and targeted infrastructure investments. Furthermore, cross-sectoral collaboration, including standard-setting bodies, tech firms, and municipalities, should be incentivized to ensure interoperability and trust in circular data ecosystems. From a systems perspective, mandating DPPs alone may yield limited results. Our findings suggest that policymakers should design integrated CE strategies that not only introduce new tools such as DPPs but also strengthen the social, organizational, and institutional conditions that enable these tools to generate real CE performance. To enhance clarity and accessibility for practitioners and policymakers, the key recommendations are summarized in Table IV below.

Table 4
Summary of managerial and policy recommendations.

Target group	Key recommendations
Managers and firms	- Use configurational self-assessment to identify weak and strong enablers of CE performance. - Align digital investments (e.g., DPPs) with business model innovation and social governance. - Institutionalize sustainability through leadership engagement, training, and KPI systems. - Leverage MTaaS logic to transform traceability data into ongoing value for customers and partners.
Policymakers and institutions	- Combine DPP regulation with fiscal incentives and infrastructure investment to scale digital traceability. - Support CE ecosystem orchestration through multi-stakeholder platforms and data interoperability standards. - Promote policy mixes that jointly address technological, organizational, and social enablers of CE. - Encourage local experimentation (e.g., city-level pilots) to test MTaaS and cross-sector collaboration models.

5.3. Limitations and future research

While our survey of Dutch construction firms reveals key CE configurations, the sector specificity limits generalization; replicating the analysis in other sectors, such as manufacturing, electronics, steel, and textiles, may expose alternative patterns. In methodological terms, fsQCA offers unique strengths for exploring causal complexity but also presents inherent constraints. In particular, results can be sensitive to calibration choices, sample size, and the definition of consistency thresholds, which influence the stability and granularity of the identified configurations (Pappas and Woodside, 2021). These aspects warrant further examination through robustness checks and comparative studies using larger or cross-national datasets. Furthermore, the cross-sectional design of this study precludes insights into how firms dynamically adjust and reconfigure enabling conditions over time. Longitudinal and mixed-method approaches, combining set-theoretic analysis with case-based or ethnographic inquiry, would deepen understanding of how circular capabilities evolve in practice. Future studies should also examine ecosystem governance, especially how platform-based DPPs and other digital intermediaries coordinate, standardize, and build trust as CE strategies scale across organizations and borders. This includes the role of interoperability standards, data-governance policies, and platform orchestration capabilities in enabling MTaaS at the ecosystem level. In parallel, the growing integration of artificial intelligence (AI) into digital traceability systems calls for research on how AI-driven analytics can enhance MTaaS performance through predictive modeling, anomaly detection, and automated lifecycle optimization. Future research could also explore how such AI-driven functions interact with human decision-making and institutional governance within circular ecosystems.

Comparative and mixed-method approaches can also clarify how specific MTaaS-enabled configurations evolve across industries and institutional settings. By foregrounding the conditional role of DPPs, future research can explore how similar tools might become effective only when situated in particular ecosystems or policy contexts. To guide this agenda, Table V summarizes key research directions concerning methodological refinement, ecosystem coordination, and the diffusion of MTaaS-driven circular strategies. In our view, this study provides both a conceptual and empirical basis for advancing such efforts in the future. With its focus on the existence of multiple viable, context-specific pathways to CE performance, this study can support both scholars and practitioners in accelerating the design, implementation, and scaling of circular strategies across sectors.

CRediT authorship contribution statement

Milad Kolagar: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ali Vahidi:** Writing – review & editing, Investigation, Data curation. **Julian Kirchherr:** Writing – review & editing, Validation. **Victor Scholten:** Writing – review & editing, Validation.

Table 5
Future research agenda.

Theme	Key Research Directions	Suggested Methodological Approaches
Configurational methods in CE research	Test how calibration thresholds, sample sizes, and consistency criteria affect fsQCA robustness and generalizability.	Cross-sample replications; multi-country fsQCA; sensitivity analyses.
Temporal dynamics of CE pathways	Examine how configurational pathways evolve as firms develop digital and circular capabilities.	Longitudinal case studies; panel fsQCA; process tracing.
Ecosystem governance and coordination	Investigate how DPPs and digital platforms structure collaboration, data exchange, and trust in circular ecosystems.	Multi-level case studies; network analysis; comparative fsQCA.
Scaling of MTaaS-based models	Explore how MTaaS is diffused across sectors, identifying the enablers and barriers to adoption and scaling. Examine how AI-enabled analytics can strengthen MTaaS by supporting predictive maintenance, material flow forecasting, and adaptive circular design.	Cross-sector comparisons; mixed-method fsQCA; comparative industry studies.
Digital–institutional integration	Assess how digital infrastructures interact with governance, culture, and policy frameworks to advance CE transitions. Analyze how AI-driven traceability and decision-support tools influence institutional trust, accountability, and policy alignment in circular ecosystems.	Policy analysis; system dynamics modeling; hybrid qualitative–quantitative designs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Measurement items and factor loadings

Constructs and items	Factor loadings	Source
Digital Product Passport (DPP)		Developed by the authors
We have identified Digital Product Passports (e.g., material passports) as a potential source of competitive advantage for our organization.	0.68	
We have recognized that Digital Product Passports are likely to become a standard practice in our industry.	0.74	
We have plans to invest in enhancing our knowledge in our organization to support the implementation of Digital Product Passports.	0.82	
We have plans for expanding our financial resources and investments for the operationalization of the Digital Product Passports or will do so soon.	0.78	
Our view is that robust data security and privacy measures should be considered in the development of Digital Product Passports.	0.85	
Our company intends to invest in adapting its technological infrastructure (e.g., blockchain-based platforms, application programming interfaces (APIs), digital software and applications, etc.) in order to fully implement Digital Product Passports.	0.76	
Our company believes it is important to have the technological infrastructure required to incorporate Digital Product Passports into our product documentation processes and life-cycle assessment.	0.72	
We have plans to establish operational processes within our supply chain that would benefit from enhanced reliability and traceability provided by Digital Product Passports.	0.83	

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(*continued*)

Constructs and items	Factor loadings	Source
We believe that the real-time data from Digital Product Passports can be leveraged to optimize our governance and decision-making processes within our organization and throughout the broader ecosystem.	0.78	
With the adoption of digital product passports, we expect to achieve greater transparency in data and increase our supply chain efficiency.	0.73	
Inter-Organizational Cooperation (IOC)		Kusa et al. (2023)
Our company is dominated by the belief that cooperation with other organizations is beneficial.	0.75	
We intensively (often and/or with many) cooperate with other enterprises.	0.97	
We are more cooperative than our competitors.	0.68	
Cooperation with other entities enables us to introduce new products to the market.	0.72	
Business Model Innovation (BMI)		Latifi et al. (2021)
We introduced new products/services as a new value proposition.	0.78	
We introduced (or planning to introduce) new combinations of products, services, and software.	0.82	
We continuously introduced novel operation processes, routines and norms to deliver value to our customers.	0.69	
We started to collaborate and share new responsibilities with new business partners.	0.68	
We created new revenue streams and pricing mechanisms for our products/services.	0.73	
We created new ways to profit from our products and services (or a mix of them).	0.78	
Government Support Factor (GSF)		Jang et al. (2023)
Our company is aware of government's support scheme for digital transformation of our industry.	0.69	
The government has various support schemes on digital transformation of our industry.	0.74	
The government's digital transformation support scheme is detailed and stable.	0.67	
The government's digital transformation support scheme is important to enhance our company's global competitiveness strategy.	0.76	
Our company is willing to participate on government's current or future digital transformation scheme.	0.78	
Formal Controls (FC)		Rauter et al. (2023)
We perform activities to achieve sustainability innovation goals, e.g., improvements in environmental key performance indicators, desired societal improvements, etc.	0.71	
Our innovation strategy includes and clearly defines our company's sustainability mission statement.	0.75	
We have clearly defined guidelines regarding our environmental objectives, e.g., reduced emissions, energy consumption, waste management, etc.	0.99	
We have clearly defined guidelines regarding our societal objectives, e.g., ethical principles, working conditions, health and safety, etc.	0.75	
We have considerations and concerns for other stakeholders, e.g., suppliers, local communities, public institutions, society, etc.	0.83	
Social Controls (SC)		Rauter et al. (2023)
Our management is a role model for sustainability and emphasizes its underlying values.	0.84	
Sustainability concerns are considered in all relevant decisions made.	0.97	
Our internal activities follow clearly defined and communicated sustainability criteria.	0.83	
Employees here have a good understanding of what sustainability means for our daily business.	0.68	
Sustainability issues are constantly present in our firm, e.g., internal newsletters, information campaigns, reports, etc.	0.72	
Circular Economy Performance (CEP)		Sahoo and Jakhar (2024)
Our company has seen a considerable improvement in the recycling rate of industrial solid waste over the past 3 years.	0.75	
Our company has seen a considerable improvement in the industrial water reuse ratio over the past 3 years.	0.89	
Our company has seen a considerable reduction in the energy consumption of per unit key product manufactured over the past 3 years.	0.67	
Our company has seen a significant reduction in wastewater discharge per unit key product manufactured over the last 3 years.	0.86	
Our company has seen a considerable reduction in industrial solid waste for final disposal over the last 3 years.	0.78	

Data availability

The data that has been used is confidential.

References

Ahmad, F., Bask, A., Laari, S., Robinson, C.V., 2023. Business management perspectives on the circular economy: present state and future directions. Technol. Forecast. Soc. Change 187, 122182. https://doi.org/10.1016/J.TECHFORE.2022.122182.

Azcárate-Aguerre, J.F., den Heijer, A.C., Arkesteijn, M.H., Vergara d'Alençon, L.M., Klein, T., 2023. Facades-as-a-Service: systemic managerial, financial, and governance innovation to enable a circular economy for buildings. Lessons learnt from a full-scale pilot project in the Netherlands. Front. Built. Environ. 9. https://doi.org/10.3389/fbuil.2023.1084078, 2023.

Balzano, M., Marzi, G., 2023. Exploring the pathways of learning from project failure and success in new product development teams. Technovation 128, 102878. https://doi.org/10.1016/j.technovation.2023.102878.

Bauwens, T., Hartley, K., Hekkert, M., Kirchherr, J., 2024. Building innovation ecosystems for circularity: Start-up business models in the food and construction sectors in the Netherlands. J. Clean. Prod. 481, 143970. https://doi.org/10.1016/j.jclepro.2024.143970.

Becchetti, Leonardo, Bova, D.M., Raffaele, Luca, 2025. Win together or lose alone: circular economy and hybrid governance for natural resource commons. J. Clean. Prod. 486, 144520. https://doi.org/10.1016/j.jclepro.2024.144520.

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D.C.A., Hildenbrand, J., Kristinsdottir, A.R., et al., 2019. Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. J. Clean. Prod. 241, 118271. https://doi.org/10.1016/J.JCLEPRO.2019.118271.

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33 (5), 308–320. https://doi.org/10.1080/21681015.2016.1172124.

Brändström, J., Eriksson, O., 2022. How circular is a value chain? Proposing a Material Efficiency Metric to evaluate business models. J. Clean. Prod. 342, 130973. https://doi.org/10.1016/j.jclepro.2022.130973.

Bressanelli, G., Saccani, N., Perona, M., 2024. Are digital servitization-based Circular Economy business models sustainable? A systemic what-if simulation model. J. Clean. Prod. 458, 142512. https://doi.org/10.1016/j.jclepro.2024.142512.

Broccardo, L., Truant, E., Dana, L.P., 2023. The interlink between digitalization, sustainability, and performance: an Italian context. J. Bus. Res. 158, 113621. https://doi.org/10.1016/j.jbusres.2022.113621.

Cainelli, G., D'Amato, A., Mazzanti, M., 2020. Resource efficient eco-innovations for a circular economy: evidence from EU firms. Res Pol. 49 (1), 103827. https://doi.org/10.1016/j.respol.2019.103827.

Çetin, S., Raghu, D., Honic, M., Straub, A., Gruis, V., 2023. Data requirements and availabilities for material passports: a digitally enabled framework for improving the circularity of existing buildings. Sustain. Prod. Consum. 40, 422–437. https://doi.org/10.1016/j.spc.2023.07.011.

Colovic, A., 2022. Leadership and business model innovation in late internationalizing SMEs. Long. Range Plan. 55 (1), 102083. https://doi.org/10.1016/j.lrp.2021.102083.

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., Worrell, E., 2019. Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. Resour. Conserv. Recycl. 151, 104498. https://doi.org/10.1016/J.RESCONREC.2019.104498.

Cramer, J., 2024. Unlocking market transformation through circular procurement: the amsterdam metropolitan area experience. Urban Sci. 8 (4). https://doi.org/10.3390/urbansci8040225.

Dagilienė, L., Varaniūtė, V., Bruneckienė, J., 2021. Local governments' perspective on implementing the circular economy: a framework for future solutions. J. Clean. Prod. 310, 127340. https://doi.org/10.1016/j.jclepro.2021.127340.

Dalenogare, L.S., Le Dain, M.A., Benitez, G.B., Ayala, N.F., Frank, A.G., 2022. Multichannel digital service delivery and service ecosystems: the role of data integration within Smart Product-Service Systems. Technol. Forecast. Soc. Change 183, 121894. https://doi.org/10.1016/j.techfore.2022.121894.

Dalenogare, L.S., Le Dain, M.A., Ayala, N.F., Pezzotta, G., Frank, A.G., 2023. Building digital servitization ecosystems: an analysis of inter-firm collaboration types and social exchange mechanisms among actors. Technovation 124, 102756. https://doi.org/10.1016/j.technovation.2023.102756.

Ebolor, A., Agarwal, N., Brem, A., 2022. Sustainable development in the construction industry: the role of frugal innovation. J. Clean. Prod. 380, 134922. https://doi.org/10.1016/j.jclepro.2022.134922.

Eising-Mertsch, L., Savaget, P., Zomer, T., Brophy, A., 2024. Frames of systems change in sustainability transformations: lessons from sociotechnical systems and circular economy case studies. J. Clean. Prod. 479, 143976. https://doi.org/10.1016/j.jclepro.2024.143976.

European Commission, 2020. A New Circular Economy Action Plan: for a Cleaner and More Competitive Europe. Report.

Favoretto, C., Mendes, G.H.S., Oliveira, M.G., Cauchick-Miguel, P.A., Coreynen, W., 2022. From servitization to digital servitization: how digitalization transforms companies' transition towards services. Ind. Mark. Manag. 102, 104–121. https://doi.org/10.1016/J.INDMARMAN.2022.01.003.

Foss, N.J., Saebi, T., 2018. Business models and business model innovation: between wicked and paradigmatic problems. Long Range Plann. https://doi.org/10.1016/j.lrp.2017.07.006, 51(1):9–21.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/J.JCLEPRO.2016.12.048.

Gieß, A., Möller, F., 2025. Exploring the value ecosystem of digital product passports. J. Ind. Ecol. 29 (2), 561–573. https://doi.org/10.1111/jiec.13621.

Gonçalves, A., Franco, M., 2024. Health product innovation and circular economy: a case study of inter-organisational cooperation in the development of a new firm. J. Clean. Prod. 435, 140502. https://doi.org/10.1016/j.jclepro.2023.140502.

Hartley, K., Schülzchen, S., Bakker, C.A., Kirchherr, J., 2023. A policy framework for the circular economy: lessons from the EU. J. Clean. Prod. 412, 137176. https://doi.org/10.1016/j.jclepro.2023.137176.

Heisel, F., Rau-Oberhuber, S., 2020. Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster. J. Clean. Prod. 243, 118482. https://doi.org/10.1016/j.jclepro.2019.118482.

Het Nieuwe Normaal, 2023. The New Normal for Buildings: a Shared Language for Circular Construction. Version 1.0). Report.

Hetherington, J.B., Loch, A.J., Juliano, P., Umberger, W.J., 2024. Barriers to circular economy adoption are diverse and some are business-model specific: evidence from the Australian cheese manufacturing sector. J. Clean. Prod. 477, 143879. https://doi.org/10.1016/j.jclepro.2024.143879.

Hidalgo-Crespo, J., Riel, A., Duberg, J.V., Bunodiere, A., Golinska-Dawson, P., 2024. An exploratory study for product-as-a-service (PaaS) offers development for electrical and electronic equipment. Proced. CIRP 122, 521–526. https://doi.org/10.1016/j.procir.2024.01.076.

Jang, H., Haddoud, M.Y., Roh, S., Onjewu, A.K.E., Choi, T., 2023. Implementing smart factory: a fuzzy-set analysis to uncover successful paths. Technol. Forecast. Soc. Change 195, 122751. https://doi.org/10.1016/j.techfore.2023.122751.

Jonker-Hoffrén, P., 2023. Policy tensions in demolition: dutch social housing and circularity. Build. Cities 4 (1). https://doi.org/10.5334/bc.305.

Kebede, R., Moscati, A., Tan, H., Johansson, P., 2024. A modular ontology modeling approach to developing digital product passports to promote circular economy in the built environment. Sustain. Prod. Consum. 48, 248–268. https://doi.org/10.1016/j.spc.2024.05.007.

King, M.R.N., Timms, P.D., Mountney, S., 2023. A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): worldviews, discrete capabilities, stakeholder requirements and concerns. J. Clean. Prod. 384, 135538. https://doi.org/10.1016/j.jclepro.2022.135538.

Kinnunen, J., Saunila, M., Ukko, J., Rantanen, H., 2022. Strategic sustainability in the construction industry: impacts on sustainability performance and brand. J. Clean. Prod. 368, 133063. https://doi.org/10.1016/j.jclepro.2022.133063.

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232. https://doi.org/10.1016/J.RESCONREC.2017.09.005.

Kirchherr, J., Yang, N.H.N., Schulze-Spüntrup, F., Heerink, M.J., Hartley, K., 2023. Conceptualizing the circular economy (Revisited): an analysis of 221 definitions. Resour. Conserv. Recycl. 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001.

Kirsch, L.J., Ko, D.G., Haney, M.H., 2009. Investigating the antecedents of team-based clan control: adding social capital as a predictor. Organ. Sci. 21 (2), 469–489. https://doi.org/10.1287/orsc.1090.0458.

Kolagar, M., 2024. Orchestrating the ecosystem for data-driven digital services and solutions: a multi-level framework for the realization of sustainable industry. Bus. Strat. Environ. https://doi.org/10.1002/BSE.3855.

Kolagar, M., Reim, W., Parida, V., Sjödin, D., 2022a. Digital servitization strategies for SME internationalization: the interplay between digital service maturity and ecosystem involvement. J. Serv. Manag. 33 (1), 143–162. https://doi.org/10.1108/JOSM-11-2020-0428.

Kolagar, M., Parida, V., Sjödin, D., 2022b. Ecosystem transformation for digital servitization: a systematic review, integrative framework, and future research agenda. J. Bus. Res. 146, 176–200. https://doi.org/10.1016/J.JBUSRES.2022.03.067.

Kolagar, M., Parida, V., Sjödin, D., 2024. Linking digital servitization and industrial sustainability performance: a configurational perspective on smart solution strategies. IEEE Trans. Eng. Manag. 71, 7743–7755. https://doi.org/10.1109/TEM.2024.3383462.

Kowalkowski, C., Gebauer, H., Kamp, B., Parry, G., 2017. Servitization and deservitization: overview, concepts, and definitions. Ind. Mark. Manag. 60, 4–10. https://doi.org/10.1016/j.indmarman.2016.12.007.

Kusa, R., Suder, M., Duda, J., 2023. Impact of greening on performance in the hospitality industry: moderating effect of flexibility and inter-organizational cooperation. Technol. Forecast. Soc. Change 190, 122423. https://doi.org/10.1016/j.techfore.2023.122423.

Latifi, M.A., Nikou, S., Bouwman, H., 2021. Business model innovation and firm performance: exploring causal mechanisms in SMEs. Technovation 107, 102274. https://doi.org/10.1016/J.TECHNOVATION.2021.102274.

Liu, Y., Tao, X., Das, M., Gong, X., Liu, H., Xu, Y., et al., 2024. Blockchain-enabled platform-as-a-service for production management in off-site construction design using openBIM standards. Autom. ConStruct. 164, 105447. https://doi.org/10.1016/j.autcon.2024.105447.

Luthra, S., Kumar, A., Zavadskas, E.K., Mangla, S.K., Garza-Reyes, J.A., 2020. Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy. Int. J. Prod. Res. 58 (5), 1505–1521. https://doi.org/10.1080/00207543.2019.1660828.

Mäkitie, T., Hanson, J., Damman, S., Wardeberg, M., 2023. Digital innovation's contribution to sustainability transitions. Technol. Soc. 73, 102255. https://doi.org/10.1016/j.techsoc.2023.102255.

Marzi, G., Balzano, M., Egidi, L., Magrini, A., 2023. CLC estimator: a tool for latent construct estimation via congeneric approaches in survey research. Multivariate Behav. Res. 1–5. https://doi.org/10.1080/00273171.2023.2193718. PubMed PMID: 37038660.

Meyer, A.D., Tsui, A.S., Hinings, C.R., 2017. Configurational approaches to organizational analysis. Acad. Manag. J. 36 (6), 1175–1195. https://doi.org/10.5465/256809.

OECD, 2024. The Circular Economy in Zuid-Holland. https://doi.org/10.1787/d568d66e-en. Netherlands. Report.

Pappas, I.O., Woodside, A.G., 2021. Fuzzy-set Qualitative Comparative Analysis (fsQCA): guidelines for research practice in Information Systems and marketing. Int. J. Inf. Manag. 58, 102310. https://doi.org/10.1016/j.ijinfomgt.2021.102310.

Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: a review of approaches. J. Clean. Prod. 215, 198–216. https://doi.org/10.1016/J.JCLEPRO.2019.01.036.

Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2021. Developing a process model for circular economy business model innovation within manufacturing companies. J. Clean. Prod. 299, 126785. https://doi.org/10.1016/j.jclepro.2021.126785.

Pollard, J., Osmani, M., Cole, C., Grubnic, S., Colwill, J., 2021. A circular economy business model innovation process for the electrical and electronic equipment sector. J. Clean. Prod. 305, 127211. https://doi.org/10.1016/j.jclepro.2021.127211.

Ragin, C., 2008. Redisigning Social Inquiry: Fuzzy Sets and Beyond. University of Chicago Press, p. 240 [Internet]. http://books.google.com/books?id=WUj9yT5zAiIC&pgis=1.

Rauter, R., Globocnik, D., Baumgartner, R.J., 2023. The role of organizational controls to advance sustainability innovation performance. Technovation 128, 102855. https://doi.org/10.1016/j.technovation.2023.102855.

Reich, R.H., Ayan, J., Alaerts, L., Van Acker, K., 2023. Defining the goals of product Passports by circular product strategies. Proced. CIRP 116, 257–262. https://doi.org/10.1016/j.procir.2023.02.044.

Rijksoverheid, 2023. National Circular Economy Programme 2023-2030. Report.

Rodrigues, J., Ruivo, P., Oliveira, T., 2021. Mediation role of business value and strategy in firm performance of organizations using software-as-a-service enterprise applications. Inf. Manag. 58 (1), 103289. https://doi.org/10.1016/j.im.2020.103289.

Sahoo, S., Jakhar, S.K., 2024. Industry 4.0 deployment for circular economy performance—Understanding the role of green procurement and remanufacturing activities. Bus. Strat. Environ. 33 (2), 1144–1160. https://doi.org/10.1002/bse.3542.

Schneider, C.Q., Wagemann, C., 2012. Set-Theoretic methods for the social sciences: a guide to qualitative comparative analysis. Set-Theoretic Methods for the Social Sciences: a Guide to Qualitative Comparative Analysis, pp. 1–350. https://doi.org/10.1017/CBO9781139004244.

Sjödin, D., Parida, V., Kohtamäki, M., 2019. Relational governance strategies for advanced service provision: multiple paths to superior financial performance in servitization. J. Bus. Res. 101, 906–915. https://doi.org/10.1016/J.JBUSRES.2019.02.042.

Suresh, J., Agarwal, V., Janardhanan, M., Saikouk, T., 2024. Unlocking sustainability: overcoming barriers to circular economy implementation in warehouse fulfilment centers. J. Clean. Prod. 485, 144391. https://doi.org/10.1016/j.jclepro.2024.144391.

The Green Village, 2020. Annual Report 2020: Fieldlab for Sustainable Innovation. Report.

Vaezinejad, S., Kouhizadeh, M., Schniederjans, D., Sarkis, J., 2025. Digital technology and the circular economy: a theoretical perspective. Comput. Ind. Eng. 206, 111225. https://doi.org/10.1016/j.cie.2025.111225.

Vahidi, A., 2025. Towards circular concrete: the implementation of circular concrete in the construction industry [Internet]. Delft University of Technology. https://doi.org/10.4233/UUID:00F97E78-D174-49EA-B5D6-00AA87E0AD7F. https://research.tudelft.nl/en/publications/towards-circular-concrete-the-implementation-of-circular-concrete.

Vahidi, A., Gebremariam, A.T., Di Maio, F., Meister, K., Koulaeian, T., Rem, P., 2024. RFID-based material passport system in a recycled concrete circular chain. J. Clean. Prod. 442, 140973. https://doi.org/10.1016/j.jclepro.2024.140973.

Van Wijnen. De Loskade, 2022. Circular Prefab Housing District (Project Overview). Report.

Verma, P., Kumar, V., Daim, T., Sharma, N.K., Mittal, A., 2022. Identifying and prioritizing impediments of industry 4.0 to sustainable digital manufacturing: a mixed method approach. J. Clean. Prod. 356, 131639. https://doi.org/10.1016/j.jclepro.2022.131639.

Wan, P.K.F., Jiang, S., 2025. Enabling a dynamic information flow in digital product passports during product use phase: a literature review and proposed framework. Sustain. Prod. Consum. 54, 362–374. https://doi.org/10.1016/j.spc.2025.01.014.

Wang, Y., Zhen, J., Wang, B., 2024. Analyzing the role of environmental policy innovations and natural resource management in driving circular economy forward: evidence from BRICS economies. J. Environ. Manag. 371, 123252. https://doi.org/10.1016/j.jenvman.2024.123252.

Wasserbaur, R., Sakao, T., Milios, L., 2022. Interactions of governmental policies and business models for a circular economy: a systematic literature review. J. Clean. Prod. 337, 130329. https://doi.org/10.1016/j.jclepro.2021.130329.

Wei, F., Feng, N., Evans, R.D., Zhao, R., Yang, S., 2022. How do innovation types and collaborative modes drive firm performance? An FsQCA analysis based on evidence from software ecosystems. IEEE Trans. Eng. Manag. 69 (6), 3648–3659. https://doi.org/10.1109/TEM.2021.3102321.

Wouterszoon, Jansen B., Duijghuisen, J.A., van Bortel, G., Gruis, V., 2023. Comparing circular kitchens: a study of the Dutch housing sector. Buildings 13 (7), 1698. https://doi.org/10.3390/buildings13071698.

Yasmeen, H., Longsheng, C., 2025. Advancing circular economy in the equipment manufacturing sector: the role of environmental management systems, innovation and policy support. J. Environ. Manag. 380, 124967. https://doi.org/10.1016/j.jenvman.2025.124967.

Zhang, A., Seuring, S., 2024. Digital product passport for sustainable and circular supply chain management: a structured review of use cases. Int. J. Logist. Res. Appl. 27 (12), 2513–2540. https://doi.org/10.1080/13675567.2024.2374256.

Zorpas, A.A., 2024. The hidden concept and the beauty of multiple “R” in the framework of waste strategies development reflecting to circular economy principles. Sci. Total Environ. 952, 175508. https://doi.org/10.1016/j.scitotenv.2024.175508.