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Article

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Leveraging digital technology capability for circular economy innovation in the food products supply chain: A mixed-method study

Abstract- Our study aims to enhance the understanding of how digital technologies function as a dynamic capability in order to improve digital circular economy (CE) innovation and food products supply chain (FSC) performance. In particular, we examine the moderating effect of absorptive capacity (AC), which remains under-studied in the sustainable operations management literature. We followed an explanatory sequential mixed-method design in this study with two main phases. In the first phase, we developed a model based on a review of the extant literature review, which was grounded in the Dynamic Capability View. We then statistically analyzed the model, using data collected from 623 respondents working in the food products and allied industries industry sector. In the second phase, primary data were collected from interviews with 10 practitioners working in 5 companies in that industry sector and secondary data from the company documents. This qualitative data was used to test the relevance and practical applicability of the model developed in the first phase. Using Structural Equation Modelling, our developed model provides empirical evidence to show that digital technology capability in the FSC positively influences digital CE innovation. We further show that AC moderates the relationship between digital technology capability in FSC and digital CE innovation. Thematic analysis of the interview data confirms digital technology capability as a higher-order capability, comprising of digital sensing, digital seizing, and digital transformation capabilities, and that digital technology knowledge absorption is a technically focused AC. The analysis further confirms the relationships between digital technology capability, digital CE innovation, and enhanced FSC performance.

Managerial relevance statement: Our findings offer practical guidance to supply chain managers in configuring appropriate resources to build dynamic (digital technology) capabilities, which would help them to "sense, seize, and transform" organizational resources and improve performance. Further, managers of business operations in the FSC should concentrate on improving their organization's AC in order to acquire and digest external data. Our study adds to the literature by shedding light on the nuanced relationships between digital technology capability in the FSC, AC, digital CE innovation, and FSC performance.

Index Terms- Digital technology, digital circular economy innovation, food products supply chain, absorptive capacity.

I. INTRODUCTION

According to the United Nations Food and Agriculture Organization, over a third of the food created for human use (1.3 billion tons annually) is lost or wasted, with both developed and underdeveloped countries wasting nearly equal amounts of food[i]. The objective of UN Sustainable Development Goal (SDG) 12, "Sustainable Consumption and Production" is to diminish food losses along supply chains, including post-harvest losses, by halving per capita global food waste at the channels and the customer levels by 2030[ii]. The sustainability of the

Food Products Supply Chain (FSC) has attracted great interest amongst academics, industry and government officials with a major focus on the Circular Economy (CE) [1], [2], [3].

Three concepts underpin the CE: 1) eradicate waste and contamination, 2) circulate goods and ingredients (at their best value) and 3) regenerate nature[iii]. Climate change, biodiversity damage, waste, and pollution are among the global concerns that CE seeks to address[4]. Previous studies have established that transforming the linear FSC to a CE can improve the sustainability of food systems [4], [5], [6], [7]. The by-products in the food industry, such as organic wastes, can be processed and used in agricultural lands for soil treatment. In contrast, other by-products, such as packaging materials, may be recycled into new products [8], for instance, fabrics for the fashion sector.

Companies like "Reborn" and "Enval" are helping food and beverage manufacturers and distributors with CE-based solutions. Food by-products are also finding new uses in the personal care industry. Keracol, a company based in the United Kingdom, has developed a line of natural colors and hair care products made from the pulp of the blackcurrant fruit. Touted as the world's greenest shampoo, "Hair o'right" created a name for itself by releasing coffee grounds-infused natural haircare products. However, there are several challenges in the path of CE-driven sustainability in Food Supply Chains (FSCs). Sharma et al. [4] identified eleven CE-driven sustainability issues, with a lack of technology and appropriate techniques as common problems.

Recent studies link Industry 4.0 and CE to establish "Circular Industry 4.0", "Digital CE", and "Smart CE" to address some of the CE-driven sustainability challenges [9], [10], [11]. Digital technologies can help in data collection and integration and provide smart CE solutions through data analysis and automation [12]. Since technologically based CE generates delayed industrial absorption of knowledge, academics have gradually shifted their focus to a business model perspective. This necessitates an understanding of the circular business model innovation. Liu et al. [13] propose future research directions, one of which is to develop CE technology applications.

Warner and Wäger [14] show how traditional firms can build dynamic capabilities to transition to a digital economy. They state that digital transformation is a constant process of digital technology application in daily operations. However, what is lacking in the literature is details of how to apply digital technology knowledge in all digital/smart CE settings. By taking a dynamic capability view (DCV) on how digital technologies function as a dynamic capability (DC), we can help address this absence and provide a fuller understanding of how to improve digital CE innovation and performance in FSCs.

The core of CE innovation, based on circular practices, is intricately connected to efforts to minimize waste and promote material circularity [15]. This encompasses both upstream and downstream activities within the broader business ecosystem. Conversely, sustainability, in this context, involves strategies designed to protect the complex, interconnected processes and systems of the supply chain ecosystem from the significant negative impacts of carbon emissions and greenhouse gases (GHGs). There is a subtle distinction between the goals of waste minimization and material circularity, and at times, the practices employed to achieve each might seem contradictory. For example, Markman and Krause [16] illustrate that sustainable practices in supply chain management or other business activities depend on two key principles: (1) they must enhance ecological health, adhere to ethical standards to advance social justice, and improve economic vitality; and (2) they must prioritize environmental concerns first, social considerations second, and economic factors third. This includes eliminating redundancies, effectively managing connections between components, managing variables, feedback, flexibility, and connectivity. Some of these practices, such as introducing redundancies, may conflict with the overarching goal of waste reduction, as noted by Bajželj et al. [17].

Given the importance of both digital technology-driven innovation and sustainability for the future of circular FSC, it is crucial to understand the relationship between these concepts. Specifically, how might digital technology-based innovation support or hinder supply chain sustainability? It is essential to consider how digital technology capabilities in the food supply chain can foster innovation and enhance or impede sustainable supply chain practices. In doing so, they address current environmental challenges while effectively leveraging emerging technologies in their development, adoption, and validation. Therefore, achieving sustainability across supply chain networks can be seen as an opportunity to adopt and implement digital technology-based innovation, aiding in sustainable business performance and uncovering new business models [18].

There is a need to better understand the relationships between digital technology capability, digital CE innovation, and improving CE performance in FSCs [19]. Whilst previous studies have examined the individual impacts of digital technology capability and CE practices on performance [20], limited research exists on their combined effects and interactions within the FSC context. FSCs face unique challenges related to waste management, resource efficiency, and sustainability, which it is posited, can be effectively addressed by integrating digital technologies and CE principles [21]. By studying the above relationships, we aim to provide valuable insights into the specific mechanisms, strategies, and best practices that can drive sustainable and efficient operations in FSCs in the context of CE. This will enable the offering of guidance to organizations in the FSC who are seeking to leverage digital technologies and CE approaches to enhance their performance. Therefore, our first research question (RQ) is:

RQ1: How does digital technology capability influence FSC management performance, with digital CE innovation acting as a mediator?

Extant literature suggests that absorptive capacity (AC) is essential to effectively utilize knowledge from outside the organization (for instance, assimilation of a firm's information systems) [22]. Furthermore, such capacity is a dynamic capability to achieve sustainable competitive advantage (flexibility, innovation and performance) [23], [24]. Knowledge is transferable and its management is critical for innovation [25]. Knowledge protection strategies of inter-organizational partners can reveal how practice can restrict and enhance knowledge absorption [25]. According to Rothaermel and Alexandre [26], AC plays a moderating role and can strengthen or weaken the relationships between exogenous and endogenous constructs. Further, AC allows a firm to realize the benefits of ambidexterity in technology sourcing. A review of the literature shows that research has not studied situations where AC can assist firms involved in FSCs in realizing the benefits of digital technologies and improving their digital CE innovation. To bridge this gap, we examine the role of AC in CE innovation. Accordingly, we propose the second RQ:

RQ2: How does absorptive capacity moderate the path of digital technology capability and digital CE innovation in FSC?

The remaining paper is organized as follows: in the next section, we set out the theoretical underpinning for our research. We focus on the Dynamic Capability View and its link to model building. We then provide the derivation for our hypotheses. In the following section, we set our research method: the mixed-method research design; empirical study in phase one; and the qualitative study in phase two. We finish with a discussion of the results, highlighting the implication of our findings for theory and practice, the limitations of our study and suggestions for future research.

II. THEORETICAL UNDERPINNING

A. Dynamic Capability View (DCV) and Model Building

A company's ability to integrate, grow, and reorganize internal and external competencies in response to rapidly changing conditions is known as its dynamic capability (DC) [27]. The fundamental blocks of the dynamic capability view (DCV) are factors of production, resources, organizational routines, core competencies, DC, and end-products. The resources are unique assets to a company and are difficult to duplicate. When firm-specific resources are grouped together in cohesive clusters spanning persons and groups to facilitate the completion of certain tasks, organizational routines and processes are created [27].

DCV theorizes that various lower-order capabilities are combined to develop a higher-order DC [28]. DCs are made up of several well-known processes [29], and are a source of sustained competitive advantage [27]. The power of DC to change the resource base, namely, produce, integrate, recombine and release resources. This is what makes it valuable. There is a distinction between ordinary and dynamic capabilities [30]. The goal of ordinary capabilities is to improve business function efficiency, whereas DC aims to align client needs with their technical and business possibilities. A capability, whether ordinary or dynamic, can be used to achieve superior results in the face of adversity. The end outcome of ordinary capability is to improve efficiency, whilst the effect of DC is to achieve evolutionary fitness (innovation) [31].

A typical FSC consists of many actors, including farmers, processors, distributors, retailers and consumers. The flow of food goes downstream while money flows upstream and information flows both ways[iv]. According to Ahumada and Villalobos [32], considerations such as the perishable nature of fresh food and its shelf life in each step of the SC make operations planning highly challenging for firms. In FSCs, there are several CE practices that enable the reprocessing of waste and garbage into new products. One example is food waste recycling, where food scraps from processing, distribution, and consumption can be converted into animal feed, organic fertilizers, or used for bioenergy production. Another practice is packaging recycling, where materials like plastic, glass, or cardboard are recycled and transformed into new packaging products, reducing waste and the need for virgin materials. Composting is another approach where organic waste, such as fruit and vegetable peels, is used to create nutrient-rich soil amendments for agricultural use, reducing reliance on chemical fertilizers. Biomass conversion involves converting waste like agricultural residues or food processing byproducts into biofuels or feedstock for bioplastics. Lastly, upcycling allows for the repurposing of food byproducts or imperfect produce into value-added products, such as transforming surplus fruits into jams, juices, or dried snacks. These practices contribute to reducing waste generation, conserving resources, and promoting a more sustainable and circular approach to food production and consumption in the supply chain [33], [34].

We suggest that digital technology capability in FSC is vital for enhancing FSC performance. Digital technology capability refers to the ability of firms to integrate Industry

4.0 advanced digital technologies, such as the Internet of Things, big data analytics, artificial intelligence, and Blockchain technologies, into their operations [10], [13], [35]. We further suggest that AC acts as a moderating factor, influencing the strength and effectiveness of the relationship between digital technology capability, digital CE innovation, and FSC performance.

In this study, we conceive digital technology capability as a first-order capability, i.e., a dynamic capability that comprises zero-level capabilities such as digital scouting, digital mindset, rapid prototyping, strategic agility, navigating innovation, and redesigning internal structure. Digital technology capability in the management of the FSC refers to an organization's proficiency in using digital tools, systems, and platforms. It involves adopting digital technologies. FSC management performance measures the effectiveness and efficiency of the supply chain, including metrics such as cost reduction, improved delivery times, customer satisfaction, waste reduction, traceability, and stakeholder coordination [12].

Digital CE innovation applies digital technologies and strategies to create a sustainable and circular FSC [36]. It involves redesigning processes, products, and systems to minimize waste, maximize resource efficiency, and promote circular practices. In this context, digital CE innovation acts as a mediator, facilitating the impact of digital technology capability on FSC performance by driving circular and sustainable practices. It enables waste reduction and resource efficiency by implementing technologies that optimize resource usage and minimize waste streams. It promotes reverse logistics and recycling through digitized processes, reducing waste and recovering valuable resources. Additionally, digital CE innovation facilitates product lifecycle management by tracking products from sourcing to disposal or recycling, optimizing design, and extending product lifespan. It also encourages collaboration and ecosystem integration among FSC stakeholders, enabling circular practices and resource circularity. Moreover, digital CE innovation enhances consumer engagement and transparency by providing information on product sustainability and circularity through digital tools like mobile apps and blockchain platforms [21].

Various digital CE innovations in the food and allied industries drive sustainability and waste reduction. Companies like "TE-FOOD" and "FoodLogiQ" use blockchain and Radio Frequency Identification to track food products, promoting transparency and preventing waste. Startups like "Winnow" and "Leanpath" employ AI and data analytics to measure and analyze food waste, helping businesses optimize ordering and menu planning. Digital tools, like remote sensing and drones, enable precision agriculture, minimizing waste through optimized resource usage. Online platforms like "OLIO" and "ShareWaste" connect surplus food with those in need, fostering a sharing economy and reducing food waste. Vertical farming leverages IoT and data analytics to enhance resource efficiency and minimize waste in fresh produce production. These examples demonstrate how digital technologies are being leveraged to create a more circular and sustainable food and allied industry. Hence, by leveraging digital CE innovation, organizations with digital technology capability in the management of the FSC can drive circular and sustainable practices, ultimately improving performance.

Based on the preceding discussion, we conceptualized the research model, which postulates that digital technology capability in the FSC leads to enhanced FSC performance; further, CE innovation mediates the process and AC plays a moderating role.

B. Hypotheses Development

1) Digital technology capability and digital CE innovation in FSC

Traditional industries must embark on digitalization projects to survive in the era of Industry 4.0. Businesses harness new technologies such as AI, cloud-based computing, Blockchain, and IoT to improve their operations [14], [37]. Hence, the development of dynamic capabilities for digital transformation is triggered by disruptive digital technologies [14], [38]. Business model innovation is critical in digital conversion. It is important to be agile to take advantage of technical and business opportunities as they arise [14]. Firms must improve their digital maturity to achieve digital transformation [14]. Based on the study of Warner and Wäger [14] we conceptualize that digital technology capability in the food products SC is formed by digital sensing, digital seizing and digital transforming. Digital sensing is further comprised of digital scouting and digital mindset. Digital seizing comprises rapid prototyping and strategic agility and digital transforming comprises navigating innovating ecosystems and redesigning internal structures. Developing digital technology capability is crucial to achieving CE performance [36], [39].

In addition, Liu et al. [12] provide a framework which links digital functions (automation, analysis of data, data gathering and integration) with CE strategy. Digital functionalities help extend the life of products and parts. It can also stimulate industrial synergies; enable predictive maintenance; support product design, remanufacturing, reselling and sharing of goods; and increase energy efficiency [12]. Digital technological skills can spur digital CE innovation, enabling restoration of ecology, component recirculation, and material life extension [40], [41]. Enhanced technological capability is linked to more exploratory innovation, when strategic flexibility is present [42].

So, we suggest that digital technology capability within the FSC positively influences digital CE innovation [119], promoting sustainability and circular practices. By integrating digital tools, FSC organizations can drive digital CE innovation, leading to enhanced sustainability and circularity [43], [44], [45], [46], [47]. Hence, we hypothesize:

H1: Digital technology capability in the FSC positively influences CE innovation.

2) Moderating role of AC

The aptitude of a firm to learn from external sources of knowledge is referred to as its AC [48]. Firms must recognize the importance of new, external information, assimilate it, and then apply it to their business [48], [49]. Re-conceptions have occurred since the original introduction of AC in 1990. For instance, Zahra and George [50] offer a new argument for potential and realized AC. They visualize AC as a dynamic capability and propose that acquisition, assimilation, transformation and exploitation of new external knowledge can be combined to create competitive edge [50]. Marabelli and Newell [25] study AC from the practice perspective of knowledge and power, proposing a framework that includes several antecedents influencing the AC process and the outcomes of superior innovation, competitive advantage and better firm performance [25].

Building on Marabelli and Newell [25], we argue that informal networks and communication, prior knowledge, organization structure, management cognitions, and alliance management systems influence the digital technology absorption process and improve CE innovation. Rothaermel and Alexandre [26] have examined the moderating role of AC. When an organization possesses high AC, it can effectively understand and integrate digital technology capabilities into FSC operations, leveraging digital tools, systems, and platforms to enhance performance. This capacity enables organizations to grasp the potential of digital CE innovation and successfully adopt and implement circular practices within the FSC [51]. In summary, AC acts as a moderator, influencing the strength and effectiveness of the relationship between digital technology capability, digital CE innovation, and FSC performance, with higher AC leading to greater benefits and improvements in FSC performance, through the integration of digital technology capability and digital CE innovation. Hence, we hypothesize:

H2: AC moderates the relationship between digital technology capability in the FSC and CE innovation.

3) Digital CE innovation and FSC performance

Kristoffersen et al. [40] refer to digital technology-driven CE as smart CE. In this study, we refer to it as digital CE innovation, a concept that can support the achievement of SDG 12 [40], and improve business performance. As previously discussed, digital functions can create new value in FSCs; for instance, IoT can capture the actual figures related to daily waste and losses of food during processing, packaging, storage and transportation. Big data analytics can help analyze large datasets and provide useful insights for decision-makers who are developing new strategies [52]. This technology can predict the events impacting digital CE innovation practices in the FSC. CE innovation also supports lean production system enabling firms to improve their financials [10], [40], [53]. Several food companies are actively implementing digital CE innovations to enhance their FSC performance. Notable examples include “Nestlé”, which promotes transparency and traceability through digital platforms like “OpenSC; Danone”, which utilizes digital solutions for traceability and waste reduction; “Walmart”, known for investments in blockchain and IoT technologies to improve traceability and quality control; and “Unilever”, which optimizes production processes and sustainability through digital platforms and data analytics. These companies are among many in the food and allied industries embracing digital technologies to drive sustainability and circular practices within their SCs. Hence, we hypothesize that:

H3: Digital CE innovation positively influences FSC performance.

4) Digital technology capability and FSC performance

IT capabilities have demonstrated a positive and significant effect on SC performance [35]. Khin and Ho [54] confirm that digital technology capability improves firm financial and non-financial performance. Data gathering, storage, and analysis relating to suppliers and customers can all be aided by digital technology skills [35]. Because agri-products are perishable by nature, digital technology competence can help organizations reduce waste and become leaner, which is vital to FSC management. As a result, overstocking can result in economic losses if items do not sell quickly enough [55]. The most significant advantage of digital technologies is their ability to monitor and trace products and, thereby, ensure their quality and longevity [56]. Several firms in the food and allied industry have developed digital technology capabilities to enhance their performance: For instance, “McDonald's” has embraced digital technology by implementing self-ordering kiosks, mobile ordering apps, and digital menu boards to improve customer experience and streamline operations. “HelloFresh” leverages digital technology through its platform, allowing customers to customize meals, track deliveries, and receive personalized recommendations, enhancing convenience. "Kroger" has invested in technologies like shelf-scanning robots and mobile scanning apps to improve inventory management and overall efficiency in their supermarkets. "Tyson Foods" utilizes data analytics and IoT devices to optimize production processes, ensuring quality control and reducing waste. "Starbucks" enhances customer experience and operational efficiency through their mobile app, enabling mobile ordering, personalized offers, and data-driven inventory optimization. These firms demonstrate how digital technology capabilities have been harnessed to enhance performance in various aspects of their operations. Hence, we hypothesize:

H4: Digital technology capability in the FSC positively influences FSC performance.

5) Mediating role of digital CE innovation

Marabelli and Newell [25] explain that AC leads to innovation. We posit that enterprises in FSC absorb information from formal and informal networks and learn about various digital technologies, which they then use to improve their innovation. When a company develops CE innovation, it achieves better FSC results [57]. Digital food waste reduction tools can uncover the sources of food waste and help businesses optimize their operations [57]. Digital CE platforms also offer various solutions for food processors that aim to improve economic and environmental performance, e.g., the "WaVa" platform)[v]. The CE Hub (CEH) and the Digital Platform for CE (DPCES) were created to support the transition to CE business models in Serbia. These platforms aim to achieve significant cost savings[vi]. New online tools are popping up to fight food waste! Platforms, like "OLIO" and "FoodLoop," use apps and websites to connect people with extra food to those who can use it. "OLIO" lets individuals and businesses share leftovers with their neighbors, while "FoodLoop" connects stores and restaurants with manufacturers who can buy their imperfect produce at a discount. By using digital tools to share information quickly and easily, these platforms keep good food out of landfills, save money, and make the whole food system more efficient and adaptable. Studies like Khin and Ho [54] examined the relationship between digital capability and firm performance with digital innovation acting as a mediator. They found that firms must adopt new digital technologies to become innovative leaders and increase business performance. Therefore, we hypothesize:

H5: Digital CE innovation plays a mediating role in the relationship between digital technology capability in the FSC and FSC performance.

III. RESEARCH METHODS

A. Research Design

We adopted a mixed-method approach with two main phases [58]. We followed an explanatory sequential design in this study [59]. In the first phase, we developed a model based on a review of the extant literature, reviewed in the previous section and which was grounded in the DCV. We then statistically analyzed the model using primary data collected from a survey. In the second phase, qualitative data were collected from interviews and secondary data from company documents. This data was used to test the relevance and practical applicability of the model developed in the first stage.

In phase one, we use PLS-SEM (SmartPLS v4 software) [60] to manage our higher-order complex research model, which simultaneously contains reflective and formative constructs (i.e., digital technological capability in FSC), successive mediation (i.e., CE innovation) and assessment of moderation (i.e., AC) effects in a uniform model [61], [62]. For the data analysis, we adopt a two-step approach for the quantitative phase of the research. The first step presents the measurement model, and the second step provides the structural model evaluation [63].

In phase two, we adopted the qualitative research study design approach suggested by Stake [64] and Mora et al. [65] to explore and understand FSC performance, which is a complex system in the context of the firm's digital technology capacity, digital CE innovation, and AC.

The study aims to enhance understanding of how digital technologies function as a dynamic capability to improve digital circular economy (CE) innovation and food products supply chain (FSC) performance. By employing both quantitative and qualitative methods, the researchers can gain a comprehensive understanding of this complex phenomenon.

The quantitative phase allows the researchers to statistically analyze a large dataset (623 respondents) to test the initial theoretical model developed based on literature review and Dynamic Capability View. This phase provides empirical validation of the proposed relationships and helps establish the foundation for the study.

The qualitative phase, conducted after the quantitative phase, involves interviews with practitioners and analysis of company documents. This phase allows for the exploration of nuances, context-specific factors, and practical implications that cannot be captured solely through quantitative methods. It helps in understanding the relevance and practical applicability of the theoretical model developed in the first phase.

By using an explanatory sequential mixed-method approach, the study employs triangulation, which enhances the validity and reliability of the findings [66]. Triangulation involves the use of multiple methods to corroborate findings, leading to stronger conclusions. This approach adds methodological rigor to the study.

B. Operationalization of Constructs

The key constructs of our study are digital technology capability in the FSC (DTC), absorptive capacity (AC), digital circular economy innovation (DCEI), and FSC performance (FSCP). The construct of digital technology capability (DTC) is considered a higher-order construct and adapted from Warner and Wäger [14]. AC is measured based on Flatten et al. [67] while DCEI is adapted from Kristoffersen et al. [40]; de Souza et al. [21]; Sgroi et al. [68] and based on expert interviews. Finally, the scale of Zeng and Lu [35] and Del Giudice et al. [69] is used to measure FSC performance (FSCP). We used firm age and firm size as the control variables since the resources and capabilities vary from small to larger firms and it will influence our studied relationships.

Before the final data collection process in phase one of our study, we pre-assessed the instrument with five senior managers working in agro-food processing firms and five academic professors specializing in supply chain management to check the wording and sequence of the items under each construct. After their feedback, we conducted a pilot survey of 43 respondents and found the internal consistency test results acceptable for each construct ($\alpha > 0.723$). Based on the results from the pilot we further revised the items to ensure that the instrument was accurate and functional for the final survey [70]. The definitions are provided in Table A1 and items under each construct are provided in Table A2.

C. Phase 1 - Sampling Strategy and Data Collection

With growing concerns about environmental sustainability, there is an increasing emphasis on CE principles globally and, like in many other countries, South African businesses are striving to integrate sustainability into their management practices[vii]. In addition, South Africa is experiencing a surge in digital transformation across various industries, including food supply chains[viii]. Hence, the country context offers rich data on adopting digital technologies to enhance operations and how such technologies improve CE practices and SC performance. In addition, the study received local funding and support, which helped facilitate access to companies for data collection.

The South African agricultural sector significantly contributes to the local and global FSC and is one of a few net processed food-exporting countries globally. The agro-food complex boosts South Africa's GDP by roughly R124 billion. The industry's top five export destinations are the United Kingdom, Netherlands, Zimbabwe, Germany and Japan[10]. South Africa is one of only a few countries that export processed foods. Grapes, avocados, oranges, and plums are among the top five exports from the country. South Africa, the eighth-largest wine producer in the world, is also establishing a reputation for producing affordable, high-quality new-world wines[ix].

The samples of this study were firms in South Africa that are members of the South African Association for Food Science and Technology (SAAFoST) and in the South African Standard Industrial Classification (SIC) codes (Version 5) (01-03: agriculture, forestry and fishery), (10: manufacturing of food products), (49-53: transportation and storage). This ensured that the sampling frame represented the desired sectors within South Africa. The 'sample ()' function, i.e., 'sample_population <- sample (database, 2300)' in R, was used to execute random sampling. The final sample included 2300 firms that spanned across agriculture, manufacturing of food products, and transportation/storage sectors, providing a diverse and representative sample of the relevant industries.

First, the survey link to our questionnaire was sent to 2300 firms in South Africa in mid-2022. We initially received 343 filled-out questionnaires after 6 weeks. Furthermore, after undertaking follow-up work, we received an additional 280 completed questionnaires after 8 weeks from the time the first reminder was sent, giving a dataset of 623 respondents for final data analysis. Based on the G power test, we found that the minimum sample size is 111. However, we collected data from 623 respondents for data analysis. The demographic profile of respondents is presented in Table A3.

D. Nonresponse Bias Test

Data were verified through a non-response bias test, which compares the data collected at the early and late phases [71]. Accordingly, a t-test was conducted on the items of key variables, such as CE innovation and absorptive capacity, using early respondents (n=343) and follow-up respondents (n=280). The results from the t-tests showed that the data collected from early respondents did not significantly differ from the late responses, hence non-response bias was not deemed an issue.

IV. PHASE 1 – EMPIRICAL DATA ANALYSIS

A. Data Analysis Technique

The present study applied the PLS-SEM method, which is very attractive to numerous researchers when it comes to the scope of a firm's digital technology and CE research [72], [73], [74] as these are new research topics. The method enables the researcher to measure and estimate complex models with reflective and formative-based models embraced with multiple constructs, indicator variables, and structural paths without striking the distributional assumptions on the collected data set [63]. In addition, PLS-SEM can produce causal-predictive base results that signify the prediction in estimating causal explanations [62].

B. Common Method Bias Test

Data were collected from a single source, meaning there is a need to be cautious about common method bias issues that could undermine the validity and influence the structural relationship of the model [75]. We adopted a procedural design and statistical test to check for common method bias issues [76]. We ensured that all responses were collected anonymously, assuring the privacy of the respondents. The questionnaire was in English, as it is the predominant language in South Africa. Sentences were simple in nature to avoid any confusion in understanding the questions. Finally, the instrument was evaluated with the same group of experts and a pilot test was conducted before the final data collection.

In the post-data collection stage, we used Harman's single-factor test to check for common method bias issues. The results show that only 25.73% of the total variance can be explained by bias, which is less than the 50% threshold [77], [78]. To complement Harman's single-factor test, we also tested the data through the full collinearity test, recommended by Kock [79]. The results show that the VIF values range from 1.796 to 2.397, which are below 3.3 for all latent constructs, suggesting that the study is free from common method bias.

C. Model Fit

The literature on PLS-SEM is still exploring the overall fit criterion for the model, as covariance-based SEM (CB-SEM), traditionally applied for theory testing, requires a detailed assessment of model fit to validate the measurement model [80]. Hence, model fit indices for PLS (Variance-based) generate fewer options than CB-SEM. In this study, we have considered model fit criteria such as standardized root mean square residual (SRMR) and normed fit index (NFI) [81]. Almost all the goodness of fit measures meets the threshold level set by previous research [82]. The results from the test revealed that the value of SRMR at 0.061 and NFI at 0.898 indicate a satisfactory level of model fit. The results indicate adequate model fit with the data [83].

D. Measurement Model (Reflective)

To test the measurement model for the reflective constructs, we evaluated it on multiple parameters, such as indicator reliability, internal consistency reliability, convergent and discriminant validity [80], [84], [85]. The standardized indicator loadings of all items are above 0.70, showing an acceptable level of indicator reliability for the constructs. The composite reliability and Cronbach alpha values of all reflective measurement variables are above 0.70, indicating an acceptable degree of internal consistency. The value of the average variance extracted (AVE) is above 0.50. This indicates the fulfilment of convergent validity in Table A4. We assessed the discriminant validity of the reflective constructs using Fornell and Larcker's [117] and Heterotrait-Monotrait ratio (HTMT) criteria. All HTMT ratio values are far below the conservative threshold of 0.850, thus, establishing convergent and discriminant validity, as shown in Tables A5 and A6.

E. Measurement Model (Formative)

To test the higher-order measurement model, we analyzed different inter-order relationships. The second-order construct DSEN (digital sensing) consists of six items (DSC=3 + DMC=3). Digital scouting (DSC) explains 79.7% and digital mindset crafting (DMC) explains 86.9% of the variance. The construct DSEI (Digital Seizing) is embedded with four items (RPR=2+ STA=2) and the extent of described variance is explained by RPR (rapid prototyping) (67.9%) and STA (strategic agility) (64.8%).

Finally, DTRN (digital transforming) relates to five items (NEI=3+ RIS=2). The degree of variance is explained by navigating innovation ecosystems- NEI (79.9%) and redesigning internal structures-RIS (57.8%). The analysis reveals that among inter-order constructs, corresponding beta coefficients (path coefficients from the first order to second order to third order) are all significant at $p < 0.05$ (see Table A7).

The results from the collinearity test show the indication of a minimum level of collinearity among the formative items with the variance inflation factor (VIF) value of all items ranging between 1.50 and 1.87. These values are far below the level of the common cut-off threshold of 5–10 [86]. Hence, the results demonstrate that the contribution of formative constructs in creating higher-order reflective and formative constructs meets the minimum threshold levels.

F. Assessment of the Structural Model

In the next step, we tested the structural model to examine the hypothesized relationships proposed in section 2. A collinearity test was conducted to examine the multi-collinearity problem among the constructs. The results show that the tolerance level of the respective predictor variables is below the critical level of VIF: 5 [63] (see Table A8).

The results from the conceptual model assessment are presented in Table A9 and Figure 2, showing that the data supports both our direct and indirect hypotheses. Hence, the respective path coefficients and their relevant R-square and Q-square values are significant. There is a significant relationship between digital technology capability in FSC performance ($\beta = 0.46$, $t = 13.49$, $p < 0.000$), digital CE innovation positively influences FSC performance ($\beta = 0.37$, $t = 8.95$, $p < 0.000$), and digital technology capability positively influences FSCP ($\beta = 0.30$, $t = 7.19$, $p < 0.000$). Therefore, all the direct hypothesized relationships, such as H1, H3 and H4 are supported (see Fig. 1).

Overall, the model shows considerable explanatory power, as digital technology capability in FSCP explains 64.8% of the variance in digital CE innovation. About 42.7% of the variance in FSCP is explained by both digital technology capabilities in FSCP and digital CE innovation combined.

We also analyzed the mediating effect of CE innovation on the path of digital technology capability and FSC performance. To conduct this mediation test, we applied the recommendations of Preacher and Hayes [87] and Hayes et al. [88]. Accordingly, we applied bootstrapping sampling distribution to analyze the indirect effect of digital CE innovation, using a 95% confidence interval. The mediating path from digital technology capability in the FSC to performance via digital CE innovation is 0.18 and significant at $p < 0.000$ (Figure 1). As the direct effect among the variables is significant, the results provide strong support for digital CE innovation as a partial mediator between these relationships, which confirms hypothesis H5 [80].

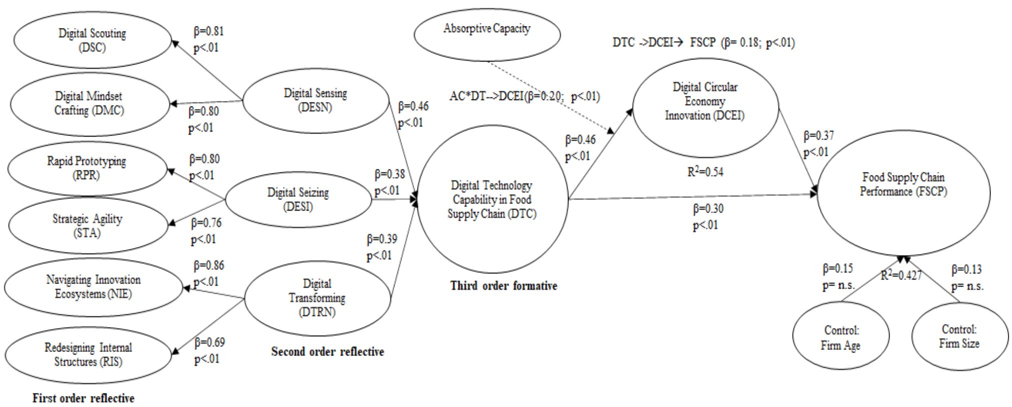

Figure 1. Tested model (Source: PLS software output)

Finally, we tested the moderation effect of absorptive capacity between digital technology capability in the FSC and digital CE innovation, by examining the interaction effect of a bias-corrected percentile method and 5,000 bootstrap resamples, as suggested by Hayes [89]. The results suggest that the moderating effect of AC is significant in the relationships of digital technology capability in the FSC and CE innovation, thus, confirming hypothesis H2.

G. Test of Endogeneity

To establish that our PLS-SEM results are robust, we examined the endogeneity issue in our tested model. We use ordinary least squares (OLS) algorithms to estimate the unknown parameters in our proposed linear regression model [90].

In the first stage of the endogeneity test, we applied the control variables, firm age and firm size, to the dependent variable, FSC performance, and in the second stage, the Gaussian copula estimated process, in line with Park and Gupta [91] and Hult et al. [92]. The 5,000-bootstrapping routine process did not find any significant effect of the two control variables on the dependent variables (firm age: β= 0.15; firm size: β=0.13), or by the control variables on the dependent variable in the tested model.

Next, we applied the "Gaussian copula" method. We examined the distribution of the variables "digital technology capability in the FSC," "absorptive capacity" and "digital CE innovation". The results from the outcome of the Kolmogorov–Smirnov test with Lilliefors correction of the standardized composite scores indicate that none of the constructs have normal-distributed scores [93]. This allowed us to perform an endogeneity test through the Gaussian copulation analysis process. Then, we added copula for each independent variable to its respective dependent variable. The results show that none of the copulas introduced in the tested model are significant. Therefore, endogeneity is not deemed an issue in estimating the relationship with FSC performance.

We also applied Hausman tests [94], [95] to the relationships between digital technology capability in the FSC and digital CE innovation (X^2 = 1.0746, d.f. = 1, p = 0.209), and absorptive capacity and digital CE innovation (X^2 = 1.0648, d.f. = 1, p = 0.018). These results show that omitted constructs are not a problem in the relationships between digital technology capability in the FSC, absorptive capacity, and CE innovation [95], [96].

V. PHASE 2 - QUALITATIVE INVESTIGATION

In this phase, we adopted qualitative studies for triangulation of results [97]. The researchers used 10 participants from five firms to conduct the study. The following section explains the steps followed for validating the empirical findings. This is an explanatory sequential mixed-method design where the quantitative approach is followed by multiple qualitative data collection and analysis methods. This design enables a deeper insight into the results from the initial quantitative analysis, with the qualitative studies verifying and providing detailed explanations [98]. Consequently, Study 2 utilized semi-structured interviews to obtain a comprehensive understanding and explanation of the findings from Study 1. A similar approach was previously used by Lin et al. [99].

A. Qualitative Research Setting

The present study adopted the qualitative research study design approach suggested by Stake [64] and Mora et al. [65]. The present study aims to answer how firms can leverage digital technology capability in the FSC through the mediating effects of CE innovation to enhance performance. In addition, we also explore the moderation role of absorptive capacity on the path joining firms' digital technology capability with CE innovation. Previous studies also applied qualitative studies considering multiple firms, leading the researchers to an in-depth understanding of the underlying mechanism [100], [101].

The study applied purposive sampling [102] to select the five firms. We used the following criteria: 1) their present business performance in the industry 2) their impact in the sector 3) their involvement in a circular FSC 4) the capability to adopt new technology and transform according to the market 5) the ability to acquire external information from large datasets and assimilate and apply it to exploit CE innovation. Data were collected to advance and authenticate the industrial applicability of our model [103], [104]. The final selected sample includes five manufacturers in the FSC located in South Africa (see Table A10).

B. Data Collection and Analysis

Data were collected through multiple sources, including semi-structured interviews and secondary data. Firstly, we conducted ten semi-structured interviews with experienced managers from the five firms at the end of 2022. These managers were all involved in decision-making regarding adopting digital technology in their respective companies.

A review of peer-reviewed qualitative research articles suggests that 9–17 participants can be sufficient to achieve saturation, particularly in studies with homogenous populations [105],

[106]. Given the exploratory nature of our research question, the present study collected data from 10 respondents, which is considered adequate for achieving initial insights. The researchers developed five semi-structured questions for conducting the entire interview, which took 40 to 60 minutes.

In the development of qualitative studies, Power [107] suggests the need to understand and attend to the principle of “logic of practice”. To improve our overall interpretation about the phenomena under investigation and further validate the findings [103], [108], we reviewed the firms’ relevant documents to triangulate across the different data sources. We analyzed the information on the firm’s website, published articles, and annual reports. We then use this information to confirm, modify or reject the evidence gathered via the interviews [103]. The data collection methods, details, aims and contribution to the findings are provided in Table A11. We analyzed the qualitative data through a data reduction process (thematic analysis) of critical interpretation and synthesis using NVivo software.

C. Data Analysis-Interview Findings

Through a data reduction process of critical interpretation and synthesis using hierarchical coding techniques, we identify five cross-cutting themes that are presented below.

<u>Theme 1: Building digital technological capability requires firms to focus on multiple elements.</u>

This is evident from the responses of below participants.

“All SC players in the FSC will be able to sense market, seize better business opportunities, credit goes to digital technologies. This is a must if you want to outperform your competitors”. – (R7) (Sales Manager)

“Building digital technologies necessitates a combination of human and technical resources. It also necessitates instilling a digital mindset, similar to what Japanese companies accomplished during TPS deployment”. - (R8) (Plant Head)

<u>Theme 2: Digital technology capability helps in digital CE innovation.</u>

This is evident from the below quotes.

“*In an effort to optimize the utilization of resources, we deploy smart devices to collect data linked to CE processes*.” *– (R4) (Environment Manager)*

“Smart contracts have helped us in executing digital CE projects” – (R5) (Chief Engineer)

“In order to address the issues with food loss and waste, we built a digital platform. Our stakeholders can use the digital platform to share resources and communicate creative ideas in order to run the CE projects efficiently”. – (R6) (R&D Engineer)

Theme 3: Digital technology knowledge absorption can strengthen/weaken the effect of digital technological capability in the FSC on digital CE innovation.

The above theme emerged from the triangulated data analysis. We provide some quotes from the participants below.

"*We look at what percentage of a company's total R&D activity is spent on developing and maintaining both internally and externally generated digital solutions*". *– (R6) (R&D Engineer)*

"We have observed that a higher level of external knowledge absorption aids in effectively enhancing the positive effects of digital technologies on innovation, which enhances the circulation of resources in FSC. What are the industry's leaders doing? What technology do they employ? What is the outcome? All of this outside knowledge saves us time and effort. Additionally, we employ the same technological service provider as the leading companies in the sector, and the outcomes are quicker and better. We can suppose that acquiring knowledge at a lesser level will not yield the expected outcomes". – (R7) (Sales Manager)

"Whatever digital technologies we use, if companies do not focus on the knowledge absorption process, the results will be poor. It takes time to build such capacity, and it may be necessary to unlearn certain expertise to chase innovation". – (R9) (Chief Scientist)

Theme 4: Digital CE innovation is the key to superior FSC performance.

This is supported by the quote of the below respondents.

"We're turning organic waste into compost and giving it away for free to local farmers (with whom we have a contract), so they can use it to improve soil quality and ultimately the fruit quality. They supply the fruits that we process at our facilities and then sell to end customers through online and offline stores. Our organic products have a serial number that customers may use to track and trace the origin. This has increased client loyalty and retention, both of which are critical in today's competitive industry". - (R4) (Environment Manager)

"We developed novel reverse logistics solutions using a combination of digital technologies (i.e., big data and AI) that resulted in a 23 percent reduction in operations costs in the previous fiscal year". - (R3) (Supply Chain Manager)

Theme 5: Digital technology capability is essential for enhancing FSC performance.

This is evident from the responses of the following participants.

"Digital technology encompasses modern information and communication technologies such as big data analytics, Internet of Things (IoT), and block chain, which is steadily gaining traction in the FSC network in South Africa. In the last two years, we've drastically reduced food loss and waste". – (R2) (Environment Manager)

"Food processing companies must seriously adapt to digital technologies or risk going out of business in the long run". – (R7) (Sales Manager)

Theme one focused on the role of digital technology capability as a higher order capability comprising of the following sub-capabilities a) digital sensing b) digital seizing and c) digital transformation capabilities. These sub-capabilities have various sub-dimensions, such as digital sensing (digital scanning of environment, digital vision), digital seizing (quick prototyping) and digital transformation (digital networking, redesign organization systems). Ordinary capabilities that aid in the construction of the DC are found in a mix of skilled employees, out workers, facilities, and machinery, and as well as procedures, routines and administrative coordination. The findings of our qualitative study match the conceptualization of digital technology capability by Warner and Wager [14]. Theme two revealed the relationship between digital technology capability and digital CE innovation. Theme three indicated that digital technology knowledge absorption is a technically absorptive capacity, possibly exerting a moderating effect on the digital technological capability in the FSC and digital CE innovation. Theme four established a relationship between digital CE innovation and enhanced FSC performance. Lastly, theme five illuminated the relationship between digital technology capability and improved FSC performance.

VI. DISCUSSION, IMPLICATIONS FOR THEORY AND PRACTICE, LIMITATIONS AND POTENTIAL FOR FUTURE RESEARCH

A. Discussion

The difficulties faced by supply chain managers when it comes to following environmentally friendly management practices are well-documented in literature [109], [110], [121], [122]. However, the complexity of FSC-related CE processes discourages many FSC participants from implementing CE [111]. The market uncertainties and low visibility further make the food manufacturers practicing CE susceptible to disruptions. Our findings corroborate with previous studies where they have indicated that digital technology capability has a positive effect on the CE and firm performance [14], [112], [113], [118].

We used a mixed-method approach to make our study more robust. We provide empirical evidence to show that digital technology capability in the FSC positively influences digital CE innovation, which we believe is a unique contribution to the CE literature. Conventionally, AC has been modelled as a direct relationship. In contrast, we consider it a moderating variable [26] and our empirical evidence suggests that AC moderates the relationship between digital technology capability in FSC and digital CE innovation. This implies that the higher/lower the AC, the stronger/weaker the effect of digital technology capability on digital CE innovation. This is also a unique insight which adds to the CE literature. Previous studies have shown a positive relationship between CE and SC performance [10], [40]. However, looking at the potential of digital technologies, we re-conceptualize the relationship between digital CE innovation and FSC performance and find that the effect of digital CE innovation on FSC performance is positive and significant.

We empirically prove that digital CE innovation mediates the relationship between digital technology capability in the FSC and its performance. This is a critical discovery, especially at a time when the world is witnessing the growth of many digital CE platforms (e.g., WaVa platform, DPCES in Serbia, etc.) that help attain more excellent FSC performance. However, research is scant on examining these relationships. We feel that our discovery will help to connect theory to emergent practices and, undoubtedly, lead to new research areas. In addition, the literature suggests there is a positive relationship between IT capabilities and firm performance [54]. Our current study examines the relationship in the context of digital technology capability in the FSC, empirically testing the relationship between digital technology capability in the FSC and its performance. As such, our findings lay the foundation for further studies in the FSC. The empirical research findings are supported by the qualitative analysis including interview data analysis findings and document analysis. For instance, a review of the themes shows that firms in this sector wish to implement digital technology capability at the organizational level or in specific areas, such as sensing, seizing and transforming abilities through digital mindset crafting, scouting, rapid prototyping, and strategic agility, navigating innovation ecosystems and redesigning internal structures. As such, FSC firms can also apply innovation in line with CE to enhance FSC performance. The findings highlight the importance of a firm's absorptive capacity in empowering managers to enhance digital CE innovation and enact resilient social and environmental practices.

The findings from the qualitative analysis using data collected from various sources ensured the rationality of the qualitative findings, quantitative findings, and literature, which further helped in the triangulation of the results.

B. Theoretical Implications

Many researchers have criticized DCV because the definitions of dynamic capability have not been fully specified. Furthermore, the term "dynamic capability" is perceived to be hazy and imprecise, impeding the theory's advancement [114], [115], [116]. To address this issue, we take a few crucial steps: first, we unambiguously define the term "technical capacity". We show that technical capacity is a higher-order construct, as suggested by Warner and Wäger [14]. Second, we build an easy-to-understand model to depict the relationships between digital technology capability, digital CE innovation and FSC performance. We demonstrate how dynamic capabilities, in this case, digital technological capability, lead to competitive advantage i.e., digital CE innovation and, ultimately, higher FSC performance. A key finding is that absorptive capacity is a moderating variable and the interactions are clearly described. From a DCV perspective, such a contextual component as AC has not been employed before. We, hence, argue that our novel findings make an important theoretical contribution.

Therefore, the theoretical contribution of our research lies in its application of the DCV to examine the relationship between digital technology capability, digital CE capability, and FSC performance. By considering digital CE capability as a mediator and AC as a moderator, we provide a comprehensive understanding of how these factors interact and influence FSC performance. Hence, we contribute to the supply chain body of knowledge by highlighting the importance of digital technology capability and digital CE capability in driving performance outcomes. Additionally, by incorporating AC as a moderator, we emphasize the role of organizational capacity to absorb and utilize external knowledge and technologies in enhancing the relationship between digital capabilities and FSC performance. To summarize, the unique contribution of this research lies in its integration of digital technology, CE, dynamic capability view theory, and AC to provide valuable insights into the complex dynamics of digital transformation and sustainability in the FSC.

C. Practical Implications

We provide three key takeaway points for managers:

First – emphasize building dynamic capabilities, in this case, digital technology capability. Building digital technology competence necessitates technology readiness and integration into company processes, which, in turn, requires the configuration of the appropriate resources. Technology capability will provide the ability to sense, seize, and transform abilities, aiding FSC firms in improving their supply chain performance. Furthermore, managers in FSCs can develop policies and action plans to build digital technology capability by following a systematic approach. They should assess the current state of digital technology capabilities, set clear objectives aligned with the organization's strategy and identify key digital technologies. A roadmap outlining the steps, timeline, and resource allocation needed for implementation would be useful. Securing leadership support, building cross-functional teams, investing in talent development, and monitoring progress through metrics and evaluation are essential. These steps will enable managers to leverage the benefits of digitalization, enhance performance, and foster a culture of innovation in the FSC.

Second - focus on digital CE innovation. Firms should not overlook the role of digital CE innovation, which acts as a mediator and aids it in achieving the outcome of the relationships. Managers should cultivate an environment that promotes innovation and actively encourages employees to participate in generating ideas and proposing solutions for digital CE innovation.

Third - focus on knowledge assimilation. Businesses must concentrate on improving their absorption capacity in order to acquire and digest external data. They can look at the percentage of the total R&D activity spent on developing and maintaining internally developed techniques for digital CE practices and the rate of total R&D activity devoted to acquiring and developing externally sourced techniques for digital CE practices. Managers involved in the management of the FSC can enhance AC through the following strategies: encouraging knowledge acquisition through conferences, training and collaborations; facilitating internal knowledge sharing and cross-functional collaboration; fostering collaborations with external partners for access to expertise and emerging trends; allocating resources for training and hiring external support; promoting a culture of continuous learning and adaptation; obtaining leadership support for resource allocation; and creating a supportive environment. These strategies enable managers to enhance AC, allowing their organization to effectively acquire, assimilate, and apply external knowledge and technologies for driving digital CE innovation.

D. Limitations and Future Research

As with all empirical studies, our research has some limitations. Specifically, cross-sectional data was used, which was collected from a sample of practitioners working in a developing country. The research was conducted after a pandemic when things were only slowly returning to normal. As a result, readers should interpret the findings within these parameters and make any generalizations to different contexts with extreme caution. These limitations, though, provide opportunities for further studies. For example, our model can be tested using data from developed nations. It can also be further extended by incorporating other contextual factors such as uncertainty, knowledge characteristics, and organizational culture. Finally, future research may investigate how companies can develop their AC faster than their competitors in the same industry.

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