Smart green supply chain management: a configurational approach to enhance green performance through digital transformation

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Abstract
Purpose – While it is known that digital transformation facilitates data flow in supply chains, its importance on green supply chain management (GSCM) has not been investigated concisely. This paper aims to expand the theory of digital transformation in GSCM by investigating the interconnections between these concepts and providing an integrative view of a smart green supply chain management (Smart GSCM).

Design/methodology/approach – This adopts a configurational perspective on digital transformation and supply chain management (SCM) to investigate the different dimensions of Smart GSCM and their contribution to green performance. Therefore, this paper analyzes data from 473 manufacturing companies using regression techniques.

Findings – The results show how smart supply chain contributes to green performance through managing green relationships (external GSCM activities) and establishing green operations (internal GSCM activities). Furthermore, this paper finds partial mediating effects for external and internal GSCM activities on green performance. These findings show that smart supply chain (i.e. digital transformation strategy and front-end technologies, supported by several back-end technologies) is directly associated with higher levels of GSCM. It is specifically associated with one of the internal dimensions of green operations, namely, green purchasing activities. Hence, the findings suggest that digital transformation alone is insufficient to achieve green performance, needing a GSCM configuration to mediate this effect.

Practical implications – This study calls attention to how managers should integrate these at least three different perspectives of SCM: digital transformation, external relationships and internal operations to increase green performance.

Originality/value – As the main contribution, this study provides a configurational and holistic understanding of the different dimensions and mechanisms in Smart GSCM.

Keywords Smart supply chain, Digital transformation, Green operations, Green supply chain management, Sustainability

Paper type Research paper

1. Introduction

Digital transformation considers adopting digital technologies to increase the flow of real-time inter- and intraorganizational data and provide "smartness" to the companies' processes and technologies (Holmström *et al.*, 2019). A growing source

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of debate in academic and practical fields is how digital transformation can support the implementation of green supply chain management (GSCM) (Hohn and Durach, 2021). GSCM is considered a supply chain-wide management approach for environmental management, including strategic positioning and environmental practices to improve companies' environmental goals (Zhu and Sarkis, 2004; Zhu *et al.*, 2013). GSCM has received more attention in the past few decades due to the challenge of global warming and resources scarcity that created pressures on companies driven by legislation, public interest or competitive opportunities (Linton *et al.*, 2007; Seuring and Müller, 2008; Wilhelm *et al.*, 2018; Zhu and Sarkis, 2004). In this context, digital transformation can play a crucial role because it can help gain visibility and predict the supply chain behavior on environmental activities and its impacts which the company needs to manage to improve green performance (Silvestre *et al.*, 2020). Digital transformation also enables technologies (such as robots in production and logistics or augmented and virtual reality) to help identify and reduce waste and emissions and increase recycling and operations efficiency in the supply chain (Meindl *et al.*, 2021). These are only some of the examples from extant literature on how emerging digital technologies support green operations and GSCM.

However, while there is a growing literature on digital transformation in operations management and the development of *smart* supply chain management (SCM) (Erboz *et al.*, 2021; Benitez *et al.*, 2022), its specific analysis of GSCM is still limited, especially when considering empirical investigations. In Appendix 1, we provide an overview of this new and emerging field of research that investigates the intersection between these two fields (Smart GSCM and GSCM). Some prior studies have considered particular digital technologies related to either external or internal practices of GSCM (Benzidia *et al.*, 2021). However, the literature lacks a broader and integrative view of digital transformation and the entire GSCM system. Extant literature suggests that digital technologies can support specific activities of the supply chain operations, creating smart supply chains (Frank *et al.*, 2019). However, current studies reported in our literature analysis (Appendix 1) do not analyze how such digital technologies will support different supply chain dimensions when green practices are adopted. The literature is still emergent and fragmented to provide a holistic understanding of a joint Smart GSCM and GSCM. This understanding is important because green practices have a different profile than conventional SCM practices. Therefore, the digital opportunities transformation opens up might be unknown (Sarkis, 2020). Moreover, digital transformation comprises more than the set of technologies usually addressed in the literature (Appendix 1). It demands a strategic perspective of how the supply chain will be transformed by real-time data flow through digital technologies (Westerman *et al.*, 2014). Therefore, both digital transformation and GSCM are represented by several dimensions that need to be interrelated to understand better how to develop what we call a Smart GSCM system – which is a GSCM system enhanced by "smart" or "digital" technologies intended to improve the company's green performance. We summarize this in the following research question:

RQ1. What are the relationships between digital transformation and GSCM dimensions to configure a Smart GSCM perspective to support green performance?

We aim to expand the theoretical understanding of digital transformation in GSCM by investigating the interconnections between Smart GSCM and GSCM, resulting in an integrative view of what we conceptualize in this study as a Smart GSCM. To this aim, we adopt a configurational perspective (Miller, 1987) of digital transformation and SCM. It integrates strategic and operational (technological) digital transformation dimensions of smart supply chain and external and internal dimensions of GSCM to explain the contribution to green performance (Zhu *et al.*, 2013). Our investigation is based on data collection and hierarchical regression analysis from 473 manufacturing companies. Our results show the relationship between green relationships (external GSCM activities) and green operations (internal GSCM activities) and that these two dimensions have partial mediating effects on green performance. Our results also show that smart supply chain is directly associated with higher development levels of the whole external dimension of GSCM. It is specifically associated with one of the internal dimensions of green operations, namely, green purchasing activities. Furthermore, this study contributes to a conceptual and empirical definition of Smart GSCM, showing how digital transformation contributes to green relationships and green operations. Our study also defines the horizontal configurational perspective of GSCM represented by external suppliers and customers' green relationships and internal purchasing, manufacturing and packaging green activities.

We built our theoretical perspective on the configurational approach proposed by Miller (1987), which was largely adopted and discussed by operations and SCM researchers (Flynn *et al.*, 2010). This theory suggests that the firm structure is defined by a holistic interaction of the different organizational subsystems, which can be represented by structure, processes and strategy, which results in particular configurations of the organization (Miller, 1987). The performance of a firm will, therefore, depend on how the company configures the different dimensions that represent its operations (Hult *et al.*, 2006). Because supply chains have a complex structure with several stakeholders and activities being coordinated simultaneously, the integrative view of the configurational approach can comprehensively understand supply chain operations and relationships (Flynn *et al.*, 2010).

In our study, we analyze two configurational levels. We first consider the configuration of a smart supply chain through digital transformation. In this view, we consider a vertical internal configuration of the digital transformation. A vertical configuration considers that organizations will integrate different hierarchical layers in their processes to obtain a better configuration of their activities (Miller, 1987). We use this view to consider the integration of strategic and operational levels of the digital transformation focused on Smart Supply Chain. On the other hand, we adopt a *horizontal external–internal configuration* view to analyze GSCM. This means that the *external and internal activities* of the organization need to be configured as an interdependent mechanism of relationships to enhance operations (Flynn *et al.*, 2010). We use this view to consider *external activities* of relationship management in GSCM integrated with *internal activities* of GSCM operations. In the following, we discuss these two configurational perspectives.

2. Theoretical background

2.1 Configuring the smart supply chain dimensions through digital transformation

The study of digital transformation in SCM has been addressed from several streams that used different conceptual labels for this phenomenon. For instance, some authors have investigated the concept of Industry 4.0 in SCM (Manavalan and Jayakrishna, 2019) and the resulting Supply Chain 4.0 (Frederico *et al.*, 2020), the development of Internet of Things (IoT)-enabled supply chains (Ben-Daya *et al.*, 2019; Birkel and Hartmann, 2019; Paolucci *et al.*, 2021) or digital/digitized supply chains (Büyüközkan and Göçer, 2018). We follow the extensive literature review of Meindl *et al.* (2021) that shows the interconnection of these different concepts under a major label called smart supply chain. Smart supply chain congregates all these perspectives that have the common aim to leverage the operations of the supply chain through the adoption of digital technologies, especially those related to base digital technologies (i.e. generic digital technologies that are used in different applications and domains). These include IoT, cloud computing, big data and artificial intelligence (AI) (Frank *et al.*, 2019; Meindl *et al.*, 2021), and, more recently, also blockchain (Cole *et al.*, 2019). In summary, smart supply chain is a technological construct that results from the digital transformation of SCM (Benitez *et al.*, 2022).

The vertical configuration of the smart supply chain has been studied through two different levels, *strategic* and *operational* (Benitez *et al.*, 2022). The *strategic* level of a smart supply chain comprises the digital transformation perspective that companies want to follow for their SCM system, considering the necessary alignment of supply chain goals with real-time data flow (Benitez *et al.*, 2022; Sturgeon, 2021). Based on this, the digital transformation strategy considers the extent of digital transformation's impact on the company's view of its SCM (Nasiri *et al.*, 2020). For instance, General Electric (GE) created a large supply chain spanning an IoT platform focused on short-term results and using technologies whenever possible. Unfortunately, the company did not achieve the desired results. Its share price plummeted because GE Digital lacked a clear and objective strategy to link technologies with outcomes and performance indicators (Davenport and Westerman, 2018). Therefore, this combined approach between digital technologies' potential and a targeted implementation in the supply chain enables the smart supply chain to promote data flow in SCM activities (Pasi *et al.*, 2020; Shao *et al.*, 2021).

The *operational* level of the smart supply chain can be divided into two technological layers: *base digital technologies* and *front-end technologies* (Frank *et al.*, 2019; Meindl *et al.*, 2021). Base technologies (i.e. generic cross-cutting technologies useful in several domains and applications) for smart supply chain allow sharing of real-time data to make faster decisions and transactions. These base technologies configure technologies, such as IoT, cloud computing, big data analytics, AI and blockchain, which are useful for multipurpose in the SCM activities (Frank *et al.*, 2019; Nasiri *et al.*, 2020). When these base technologies are used as stand-alone technologies in the smart supply chain, they are concerned with the data flow in the supply chain for better integration (Aryal *et al.*, 2018). Thus, the interrelationships between buyers and suppliers, as well as aspects such as supply chain design, are changed through the use of base technologies, which provides more transparency to this integration (Frank *et al.*, 2019). In this regard, supply chain transparency is vital to enabling supply-chain spanning potentials for data analysis and optimization (Müller *et al.*, 2020).

Moreover, these base technologies can be run in the back-end to enable the operation of front-end technologies. Front-end technologies are defined as technologies that execute operational tasks like material handling or quality control of inputs in supply chain operations. Some of them are collaborative robotics, computer simulation, augmented reality or three-dimensional (3D) printing (Dalenogare *et al.*, 2018; Hohn and Durach, 2021). These technologies optimize supply chain processes, such as smart machines for packaging or sensor technologies, ensure logistics specifications and avoid damaged goods (Birkel and Müller, 2020; Frank *et al.*, 2019).

2.2 Configuring the GSCM through external–internal connections

In contrast to general SCM studies, which tend to focus predominantly on market and financial results, the GSCM field also considers social and environmental metrics to understand green performance, as in the studies from Appendix 1. Overall, the GSCM goal is to integrate environmental concerns into the entire supply chain, configuring the traditional operational processes like manufacturing and purchasing and relationships with partners into sustainable practices (Hsu *et al.*, 2016; Laari *et al.*, 2016). When companies look at green practices in SCM, they can align their operations management process to achieve green performance goals and develop GSCM systems (Abdel-Baset *et al.*, 2019; Wu and Pagell, 2011).

As the interplay of internal and external processes is highly relevant to the digital transformation of supply chains (Frank *et al.*, 2019), there is a need for studies that use theories that show how to interrelate green supply chain internal and external activities to achieve enhanced performance. Our five-year literature review on digital transformation and GSCM is evidenced in Appendix 1. Most of the studies focused on the use of specific technologies such as blockchain, IoT or additive manufacturing to support green operations or on the factors and barriers to implementing digital transformation in green operations. However, extant literature lacks evidence on the join implementation of both strategic and technological levels of digital transformation in several dimensions of GSCM. The literature in Appendix 1 acknowledges that strategic and technological dimensions set digital transformation and that GSCM requires internal and external green operations activities. These activities can be supported by digital transformation, but evidence for this is sparse and fragmented in several studies. Furthermore, a holistic and integrated view on Smart GSCM systems is still missing. Therefore, we adopt a configurational theory to explain the configuration and alignment of external activities with suppliers and customers with internal activities, e.g. manufacturing processes, to achieve higher performance (Hult *et al.*, 2006). We follow a horizontal external–internal configurational approach rather than individually studying the supply chain elements. Based on this, we propose that internal and external green supply chain activities should be interrelated to support firms in achieving green performance. Such an integrative view from external and internal activities is relevant for digital transformation. This is because digital technologies have one of their main aims to integrate data flow from different organizational levels (Frank *et al.*, 2019).

According to Zhu *et al.* (2013), some companies have already understood how to interrelate green relationships (external configuration) and green operations (internal configuration) into a GSCM system to achieve higher green performance. These companies started green internal practices before expanding their activities to external relationships at GSCM because they can have a higher control and management of their green practices. However, implementing or developing solely internal green operations requires large efforts to achieve green performance. Companies depend on external activities such as material, components and subcomponents and environmental compliance with customers in the product development process (Seuring and Müller, 2008). Companies are further dependent on interconnecting internal and external activities to gain green performance (Birkel and Müller, 2020). For instance, reducing resource and energy consumption should be aligned among purchasing, manufacturing and packaging processes to achieve better results, but this will also depend on the quality of inputs received from supplies.

Despite studies in GSCM exploring how external and internal activities are important for performance separately (Appendix 1), there is still a lack of studies investigating how these external and internal levels can be interrelated for the improvement of green supply chain results. Therefore, we integrated the configurational approach to comprehend how the interrelated activities between internal operational activities (green packaging, green manufacturing and green purchasing) (Hsu *et al.*, 2016), and external relationship activities (green supplier relationships and green customer relationships) (Laari *et al.*, 2016) could improve green performance. We aim to understand how this configurational approach of GSCM can be supported by the digital transformation perspective of smart SCM to configure a holistic Smart GSCM that enhances firms' green performance.

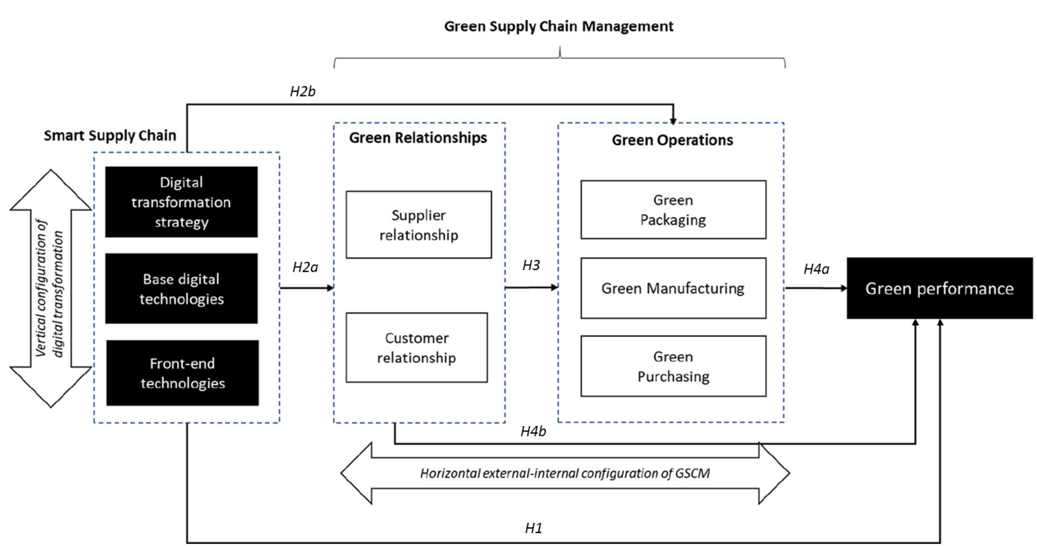
3. Hypotheses development

Our investigation of the recent literature on digital transformation and GSCM described in Appendix 1 shows that such literature still lacks an overall framework for what we call Smart GSCM. Better, we show the relationships between the several dimensions of digital transformation in the supply chain (smart supply chain) and GSCM (i.e. the internal and external green practices and activities of the supply chain). Our hypotheses aim to fulfill this gap by providing a framework that defines through empirical analysis what we call as Smart GSCM. Thus, we aim to contribute by showing how these dimensions are related and how the Smart dimension contributes to the GSCM dimensions to increase green performance. This is represented in our conceptual model of Figure 1, which also illustrates our theoretical perspective on the vertical configuration of digital transformation and the horizontal external–internal configuration of GSCM to structure our view of Smart GSCM. Figure 1 also illustrates how our hypotheses discussed next aim to integrate the Smart GSCM and GSCM dimensions and connect them to green performance. Therefore, the validation of such hypotheses can provide a general theoretical understanding of the main elements of Smart GSCM, which can also support practical implementations. These two contributions fill gaps in the literature described in our analysis (Appendix 1). Following, we discuss the details of the hypotheses proposed.

3.1 Smart supply chain and green performance

The literature of digital transformation in GSCM described in Appendix 1 has already acknowledged the use of concepts such as Industry 4.0 (Belhadi *et al.*, 2021), digital technologies (Bechtsis *et al.*, 2021) or digital transformation (Zekhnini *et al.*, 2021) connected to green performance. Several studies identified in the literature of Appendix 1 use a broad approach by connecting the digital transformation issue with sustainable

Figure 1 Conceptual model for smart green supply chain management relationships



operations rather than only environmental issues (green performance). On the other hand, they tend to focus on specific parts of the digital transformation, either on the strategic side or on the technologies adopted. We use an integrative perspective of what we call smart supply chain to investigate its impact on green performance. In this view, smart supply chain comprises the configuration of three different hierarchical layers: digital transformation strategy, base digital technologies and front-end technologies, and each of them could have contributions to increasing green performance.

The *digital transformation strategy* can create new business models that provide a new green perspective for the companies to use the generated data toward a strategic position as a green performer in the market (Birkel and Müller, 2020; Hohn and Durach, 2021). Furthermore, besides the digital strategy, *base technologies* are crucial for green performance because cutting-edge technologies like IoT, cloud, big data and AI facilitate companies' data flow and management. Several studies in the literature (Appendix 1) have concentrated their focus on this digital dimension, suggesting that tools like blockchain or cloud systems can improve transactions and monitoring of the green practices, which results in better performance (Cole *et al.*, 2019; Gong *et al.*, 2022). Furthermore, as suggested by Frank *et al.* (2019), data-driven technologies enable the implementation of *front-end technologies*. These front-end technologies (e.g. simulation, 3D printing, augmented reality) are responsible for smart supply chain implementation, enabling digital platforms with customers and suppliers to maximize green performance, e.g. virtual testing instead of physical prototypes. When companies use front-end technologies strategically, they can also create new industrial applications, improving their competitiveness and promoting their sustainability success (Frank *et al.*, 2019; Zhao *et al.*, 2010). Hence, we propose the following general hypothesis to represent these three dimensions of the smart supply chain:

H1. Smart supply chain is positively associated with higher levels of green performance.

3.2 Smart supply chain as an antecedent of GSCM

Even though smart supply chain plays an important role in green performance, it also depends on the green supply chain configuration. Companies should structure their external and internal practices to align with their environmental goals (Sarkis *et al.*, 2010; Wu and Pagell, 2011). Hence, according to the configurational approach, the best results in green performance cannot be reached in a supply chain only by using digital strategy and technologies. It also needs to be aligned between external activities (green relationships) and internal activities (green operations). Without this alignment, companies are improving their processes and practices without a clear perspective. Consequently, they deliver short-term transitory results rather than implementing changes that will improve long-term and lasting sustainable results (Wu and Pagell, 2011). Hence, companies need to rethink how they can organize green relationships and green operations in conjunction with smart supply chain to promote green results (Birkel and Müller, 2020). Companies are developing new digital strategies focusing on improving their data flow, adopting base technologies like cloud services to facilitate the information sharing between their process and adopting front-end technologies to improve processes themselves (Frank *et al.*, 2019; Wu and Pagell, 2011). Thus, companies can reach a higher level of competitive advantage toward sustainability when they join efforts to implement smart supply chain and GSCM together.

As smart supply chain consolidates the use of base technologies to improve relationships, companies are using base technologies to collect and analyze data that could create new opportunities for data management and integration towards sustainability (Frank *et al.*, 2019; (Wilhelm and Villena, 2021). In addition, front-end technologies can enhance green relationships with suppliers because companies can use these technologies to better select green supplies. On the other hand, green operations could enhance companies' performance when driving digital transformation in their supply chains. Providing information using digital platforms with suppliers can help companies develop green digital purchasing, offering new reliable, accurate information about the suppliers and explaining how they implement green practices into their supply chain (Birkel and Müller, 2020; Narayanamurthy and Tortorella, 2021). Furthermore, to deliver the products to eco-friendly customers, companies seek to create new green packages, using as few materials as possible, which can be supported by sensors connected via the IoT, to enhance such packaging solutions (Birkel and Müller, 2020; Kumar *et al.*, 2021; Narayanamurthy and Tortorella, 2021).

Considering the contributions explained by smart supply chain to green relationships and green operations, we propose the following hypotheses:

H2a. The configuration of smart supply chain dimensions is positively associated with higher levels of green relationships.

H2b. The configuration of smart supply chain dimensions is positively associated with higher levels of green operations.

As we follow a horizontal external-internal configurational view of GSCM, we hypothesize the relationship between green relationships and green operations, being both parts of the GSCM system. In the configurational view of SCM, external activities support internal operations (Flynn *et al.*, 2010), which can be extended to GSCM. For instance, green suppliers can encourage the use of renewable resources in the supply chain. At the same time, eco-friendly customers can demand new green or remanufactured products to mitigate the carbon footprint (Abbey *et al.*, 2015). These requirements from the stakeholders can stimulate new green practices (Zhu *et al.*, 2013). One of such practices is the demand for ISO 14001 certification from suppliers when companies look for supplies (Laari *et al.*, 2016; Hsu *et al.*, 2016). Although green purchasing will prioritize renewable resources for the companies' processes, companies should also rethink how they manufacture their products regarding environmental impacts. Green manufacturing can be implemented by pressure from green suppliers and customers (Zhu *et al.*, 2013), enabling them to create converging practices to integrate and align sustainable manufacturing with GSCM. Furthermore, supply chain actors can work together to improve their collective recycling systems, improve green product development and enhance recycling technology (Rahmani *et al.*, 2021). Based on the GSCM configuration, green packaging is another important practice influenced by suppliers and customers. For instance, biodegradable packaging has been a requirement from society and governments in the past few years, but its cost is still not competitive for some companies. Therefore, restaurants like iFood and Uber Eats offer green packaging that consumers are willing to pay for, promoting new green practices in packaging operations (Zhu *et al.*, 2013).

Considering these aspects, we propose the following hypothesis:

H3. Green relationships are positively associated with higher levels of green operations.

While green relationships and green operations can have stand-alone contributions to green performance (Hsu *et al.*, 2016; Laari *et al.*, 2016), the configurational view also considers relationships and alignment between the internal and external structure of the organizational system (Flynn *et al.*, 2010), as represented in Figure 1, which results in the contribution of GSCM on green performance, as hypothesized:

H4a. The development of green relationships is positively associated with higher levels of green performance.

H4b. The development of green operations is positively associated with higher levels of green performance.

4. Research method

4.1 Sampling

We conducted a cross-industry survey with experts in SCM. The target respondents were top executives and managers or directors with strategical decision-making roles in Brazil, many representing foreign multinational companies. The initial sample was composed of approximately 1,500 executives from all Brazilian regions who participate in the Brazilian Council of Purchasing and Supply Executives. We did not select any specific profile of respondents to reduce selection bias and increase the randomization of the sample. However, because companies more engaged in the questionnaire topics are more likely to participate (self-selection bias), we adopted the strategy of sending the invitation through a specific customized channel of the association (which elevates the likelihood of different types of companies to respond). We also conducted post hoc tests for endogeneity and self-selection bias (Section 4.5). Our questionnaire was sent three times to our target respondents via e-mail from the beginning of February to the end of March 2021. We obtained 615 answers with 473 final useful responses (31.5% response rate). Our final sample is composed of the majority (78%) of large companies (more than 500 employees), followed by 17% of medium-sized companies (100–500 employees) and 5% of small companies (less than 100 employees), according to the classification of the Brazilian Institute of Geography and Statistics (IBGE, 2015). The overall respondent profile was essentially of directors (40%), managers (36%), coordinators or supervisors (13%), president/vice/CEO (6%) and owners (5%). Table 1 details all sample compositions in our study.

Regarding revenue, more than 65% of our sample is composed of manufacturing companies that earn more than US$104m per year. Therefore, our sample is characterized by significant players in manufacturing industries. Approximately 25% of manufacturing companies earn between US$19m and US$104m, and only around 7% achieve less than US$19m. Moreover, considering the time of foundation, most companies (around 96%) have more than 10 years of experience in the market, while 4% have less than 10 years of experience, characterizing a relative mature business life, which is important when considering companies with consolidated supply chains as expected in our study. Hence, especially in an emerging economy like Brazil, we argue that enterprises with large revenue and experience in the market are more likely to invest in green processes to achieve new performance levels (Frank *et al.*, 2016; Cousins *et al.*, 2019; Nara *et al.*, 2021).

Table 1 Sample composition

	Description	(%)
Revenue	More than US$208m	50
	Between US$146m and US$208m	8
	Between US$104m and US$146m	8
	Between US$63m and US$104m	12
	Between US$19m and US$63m	14
	Less than US$19m	7
Company size	Small (<100 employees)	5
	Medium (100–500 employees)	17
	Large (>500 employees)	78
Respondent's profile	Director	40
	Manager	36
	Coordinator or supervisor	13
	President/Vice/CEO	6
	Owner/Partner owner	5
Active on market (foundation)	More than 10 years	96
	Between 7 and 10 years	2
	Less than 7 years	2
Industry sectors	Consumer goods	34
	Automotive	13
	Agribusiness	8
	Pharmaceutical	6
	Electronics	6
	Chemicals and petrochemicals	4
	Construction	3
	Energy	3
	Capital goods	2
	Paper and cellulose	2
	Mining	1
	Transport	1
	Others	17
Regions	South East	75
	South	14
	North East	5
	Midwest	4
	North	2

Thus, we opted to choose companies that are already consolidated in the market as those represented by the business association investigated in our sample. In addition, we also analyzed the regions of the sample. Almost 90% (75% from the Southeast and 14% of the South) of our sample are composed of manufacturing companies that are in the most industrialized area of the country (Southeast and South of Brazil) (Marodin *et al.*, 2017).

4.2 Measures and survey instruments

The questionnaire was developed from well-established constructs in extant literature. The items used to measure each construct and respective references are presented in Appendix 2. We also present which hypotheses each construct used in Appendix 2. For digital transformation, we used three constructs nominated [DT_STRATEGY], [BASE] and [FRONT_END]. The first, known as digital strategy, uses a five-item scale that comprises the strategical aspects of digital transformation, e.g. to create a stronger communication network between different sectors (Nasiri *et al.*, 2020). We also considered the exchange of information, collecting large amounts of data, and improving the interface with customers through digitalization as part of the digital strategy (Nasiri *et al.*, 2020). For the second [BASE] and third [FRONT_END] constructs, we followed Frank *et al.* (2019), who presented these nomenclatures for digital transformation technologies. For base technologies [BASE], which are cross-cutting or general-purpose technologies that organizations need to adopt along with their systems when they want to implement digital transformation. Base technologies (IoT, cloud computing, big data analytics, AI and blockchain) have a comparably broad focus and field of application. They represent the foundation for digital transformation and provide the intelligence for the systems, enabling the "smart" operations in supply chains with more specific and focused technologies (Frank *et al.*, 2019). To measure [BASE] we used a formative construct based on a five-item scale that considers digital technologies like the IoT, cloud computing, big data analytics, AI and blockchain (Frank *et al.*, 2019; Meindl *et al.*, 2021). We also included in this construct blockchain as it is considered a key digital technology that provides different applications for supply chains (Kouhizadeh *et al.*, 2021). In the case of front-end technologies [FRONT_END], we included collaborative robots, computer simulation, augmented reality and 3D printing. We based this decision on Frank *et al.* (2019) and Meindl *et al.* (2021) studies, who explain that these frond-end technologies support the development of the smart supply chain. We adopted a formative scale to represent these two constructs (BASE and FRONT_END) because each of these technologies provides different but complementary applications that constitute the digital operations of the companies (Coltman *et al.*, 2008) while they all contribute to providing an advance digital operation. Thus, these two constructs were built through a composite measure using the sum of the items.

For GSCM, we used five constructs divided into green relationships [SUPPLIER; CUSTOMER] and green operations [PACKAGING; MANUFACTURING; PURCHASING]. The green supplier relationship includes cooperation with suppliers for eco-product design, green input logistics development, mutual understanding of environmental issues responsibilities and suppliers' preference for an environmental management system (Laari *et al.*, 2016). Green customer relationship considers cooperation with customers for eco-product design and mutual understanding of responsibilities in environmental issues. The construct also has items related to customers' demands, like information on the company's environmental compliance, ensuring sustainable practices of the company's suppliers and the request to implement an environmental management system like ISO 14000 (Laari *et al.*, 2016). Green packaging includes the company's reusable packaging, the use of fewer materials, encouragement of the use of reusable packaging and promotion of packaging recycling and reuse programs (Hsu *et al.*, 2016). For green manufacturing, we considered assessing the environmental impact of developing and improving products, product development with recyclable raw material, low use of resources, low impact on the environment and high life span. In the case of green purchasing, we measured this construct with four items, including purchases based on environmental specifications established by product design and purchases conducted with ISO 14001 certified partners (Hsu *et al.*, 2016). We also included minimized environmental impact in purchasing procedures and a purchasing process that follows product labeling standards to minimize environmental impact as items for this construct (Hsu *et al.*, 2016; Green *et al.*, 2012; Zhu *et al.*, 2008).

Regarding the dependent variable, we used one main construct named green performance [GREEN_PERF], which includes performance metrics related to environmental impact in the last three years. We selected this construct as a final measure because our goal was to analyze the influence of digital transformation on the green operations and relationships in GSCM. For analyzing how green metrics are influenced in a GSC configured with interrelated relationships, we used a scale that considers an increase in material recycling, reducing of emissions, reducing of use/waste of resources and decreasing the use of hazardous and environmentally harmful materials (Cousins *et al.*, 2019; Zhu *et al.*, 2008). We measured all the constructs' items using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Usually, the control variables used in surveys are company size and the industrial sector. However, considering our context, we aim to understand if there is a department responsible for sustainable operations to understand GSCM. Hence, we included the existence of an area/department responsible for sustainable operations in the supply chain inside the firm [GO-area: 1 = yes; 0 = no]. In addition, we also controlled the firm's size, measured by the number of employees into two main dummy categories [firm_size: 1 = large; 0 = small or medium], following the Brazilian Institute of Geography and Statistics classification (IBGE, 2015).

4.3 Variable operationalization, reliability and validity of measures

To examine unidimensionality, we performed confirmatory factor analysis (CFA). Our model showed the goodness of fit as the reference values for comparative fit index (CFI), Root mean square error of approximation (RMSEA), average variance extracted (AVE), composite reliability (CR) and Cronbach's alpha fell in the acceptable values (Hair *et al.*, 2018), as shown in Appendix 2. In addition, overall constructs showed high factor loadings, the exception of one item for [MANUFACTURING], which we opted to keep as the construct is already validated in the literature (Hsu *et al.*, 2016) and a general test including all constructs of *Green Operations* showed the goodness of fit (RMSEA = 0.072; CFI = 0.925). We also measured *Green Relationships* (RMSEA = 0.081; CFI = 0.971) and *Smart Supply Chain* (RMSEA = 0.081; CFI 0.947) constructs and obtained goodness of fit in our measures. Also, the final and complete model including all constructs reported goodness of fit (RMSEA = 0.054; CFI = 0.913; $\Delta\chi^2$ = 1676.17).

We also checked discriminant validity using a series of two-factor model estimations (Bagozzi *et al.*, 1991). As recommended by Cable and DeRue (2002), we performed pairwise comparisons amid CFA models for each construct, looking for their respective goodness of fit. In the first step, the correlation between the two constructs was restricted to a unit. In the second step, the model restriction was freed, and we calculated the goodness of fit for the original constructs. In this test, all the results showed discriminant validity ($\Delta\chi^2 > 3.84$, $p < 0.01$), evidencing our constructs are measured with theoretically different concepts (Bagozzi *et al.*, 1991).

Finally, we assessed the normality of our data by examining the skewness and kurtosis values. The results suggest that our data is normally distributed since all values were between the thresholds of ± 2.58 (α = 0.01) (Hair *et al.*, 2018). We also analyzed the means, standard deviations and correlations for our constructs and control variables incorporated in the model. Appendix 3 summarizes all descriptive statistics, as well as normality and correlations.

4.4 Response bias and common method variance

Considering the potential bias in our survey design, we used a series of procedures and statistical remedies to attenuate this potential issue (Podsakoff *et al.*, 2012). Moreover, because our survey is composed of single respondents, common method variance (CMV) may be a concern (Podsakoff *et al.*, 2012). As an initial procedure, we pretested the questionnaire with 20 executives to verify the clarity of our survey instrumentation. The chosen executives were all related to GSCM and knowledge of digital transformation technologies and strategies. Then, the order of questionnaire blocks (e.g. green operations, green relationships, digital transformation and performance metrics) was randomized to prevent potential associations between the variables. To test the magnitude of CMV, we performed several statistical tests using RStudio. First, we performed Harman's single factor test in which a single factor loads on all measured items from our model. If the total variance extracted by one factor exceeds 50%, common method bias is present in the study (Podsakoff *et al.*, 2003). The single factor explained 32.61% of the total variance, indicating CMV is not a concern in our study. However, because this approach is too simple and other authors (Williams *et al.*, 2010; Simmering *et al.*, 2015) recommend other approaches to measure CMV, especially for single respondents, we also performed the marker variable technique. The marker variable technique considers adding a variable to the survey, which is expected to be theoretically unrelated to the substantive variables measured in the model (Lindell and Whitney, 2001). We used "logistics operations during the pandemic" as a marker, which is used to measure how respondents felt the impact of their logistics operations during the pandemic. We initially included this variable in the correlation matrix with all variables in our model. To GO_ AREA and DT_STRATEGY, the marker variable presents p-value < 0.05, even though this happens with two variables, CMV was not a concern in our survey. Moreover, we included this item in all estimations necessary for hypothesis testing, and the results were compared with the outputs without markers. The results remained stable with adding a marker variable, which means that there were no significant changes in the models. Hence, we concluded that response bias should not be a concern in this data set.

4.5 Endogeneity and robustness checks

Because endogeneity and self-selection bias can jeopardize and biased regression results, we also assessed this in the model (Bascle, 2008). There may be an endogeneity effect on the digital transformation process as companies may have been forced to adopt digital strategies because of the pandemic. At the same time, respondents can self-select to respond to the survey because the companies are more engaged in GSCM. To test endogeneity and self-selection bias, we ran a two-stage least squares (2SLS) regression approach in Stata 16. We instrumented all independent constructs in our model during our hierarchical regression procedure stages. We chose four items related to COVID-19 impact (i.e. demand impact, production impact, purchasing and revenues) in the industrial activities to instrument our independent constructs. COVID-19 has accelerated the adoption of digital technologies and has impacted on the supply chain operations (Zimmerling and Chen, 2021). Therefore, we considered this effect a potential instrument for choosing digital transformation development and green operations and relationships management within a supply chain configuration. According to our initial tests, the explanatory variables showed that our instruments are strong (i.e. the p-values < 0.001, and the minimum F-value is 14.41, $p = 0.000$). Therefore, we verified whether the explanatory variable should be treated as endogenous and need to be instrumented as proposed in the 2SLS regression model. We performed Stata's *estat endogenous* procedure using Durbin and Wu–Hausman statistics to evaluate the consistency of our estimators. The tests showed that the hypothesis that the explanatory variable is exogenous could not be rejected during our regression estimation (i.e. all p-values > 0.05).

We instrumented all smart supply chain constructs in the general model [GREEN_PERF] with the other constructs, which comprise all associations and relationships in our study. The results for the instrumented constructs in the general model were: Durbin = 1.741, p-value = 0.627 and Wu–Hausman = 0.565, p-value = 0.638. For the validity of instrumental variables, we analyzed the Sargan χ^2 and Basmann χ^2 tests through Stata's *estat overid* code which checks if the instruments are uncorrelated with the error term and correctly excluded from the estimated equation (Baum *et al.*, 2003). Our results for the general model were: Sargan χ^2 test = 0.161, p-value = 0.687 and Basmann χ^2 test = 0.157, p-value = 0.691.

To ensure the general consistency of our model, we also performed a series of robustness checks. We explored how the results of our regressions analysis might vary using four distinct robustness approaches:

1 removal of control variables;
2 inclusion of a new construct;
3 individual analysis from predictors; and
4 inclusion of a competitive model.

In the first approach, we removed all control variables (GO_area and firm_size) to check if our predictors were not control variables' artifacts. We found stable results because there were not significant changes in the coefficients of all models in our regression. For the second approach, we included a construct named green practices (RMSEA = 0.078; CFI = 0.986; AVE = 0.42; Cronbach = 0.72; CR = 0.98), including: use of environmentally friendly materials in packaging (0.43), purchasing of materials that do not harm the environment (0.75), assessment of suppliers' environmental compliance (0.70) and use of environmental training effectively in daily activities (0.68). We expected to find significant effects from the relationship between digital transformation and GSCM constructs since green practices are present in GSCM routines (Green *et al.*, 2012; Zhu *et al.*, 2008). The approach showed a significant direct effect of this new construct in all models, confirming the link between green practices, digital transformation and GSCM. For the third approach, we analyzed the individual effect of each construct in our models, and overall, we found consistency with our main findings presented in Table 2 in the Results section. We only have slight changes in [BASE] construct, which showed a positive association in our models when single evaluated. However, this reinforces our *H2a* and *H2b* because we found positive associations when [BASE] was single measured despite in the overall assessment with all variables, it did not show any positive and significant associations. Finally, we tested a competitive model for the fourth approach considering smart supply chain as a moderator between GSCM and green performance. However, we did not find statistical support for this competitive model.

4.6 Data analysis

We performed a set of hierarchical ordinary least squares regression models to test our hypotheses. We standardized our independent variables using a mean-centering *Z*-score to test all relationships. In the first stage, we examined all direct effects of the digital transformation phenomenon [DT_STRATEGY; BASE; FRONT_END] on green relationships [SUPPLIER; CUSTOMER]. In the second stage, we included [SUPPLIER] and [CUSTOMER] as independent variables and regressed them in green operations [PACKAGING; MANUFACTURING; PURCHASING]. In the last stage, we included green operations variables as independent and assessed them in green performance [GREEN_PERF]. We also checked the mediation effects from green relationships [SUPPLIER; CUSTOMER] on digital transformation for green operations [PACKAGING; MANUFACTURING; PURCHASING], and from GSCM on smart supply chain for [GREEN_PERF]. We performed the PROCESS macro from Hayes (2017) to assess the mediation effect. Our final model contains two control variables, eight independent variables and one dependent variable.

We checked the assumptions of normality, linearity and homoscedasticity for our regression analysis for all independent and dependent variables. We analyzed normality through the values of kurtosis and skewness (Appendix 2). Linearity was investigated by plotting the partial regressions for the independent variables, while homoscedasticity was visually examined in plots of standardized residuals against a predicted value. All these requirements were met in our dataset for regression analysis. Finally, we evaluated a possible multicollinearity issue for our independent variables, as Hair *et al.* (2018) suggested. In multicollinearity, regression estimates are unstable and have high standard errors. Our results indicate a low variance inflation factor (<3.5) for all variables far below the threshold of 10 (Hair *et al.*, 2018).

To assess mediation effects, we calculated the indirect effects of the relationships as suggested by Preacher and Hayes (2008). We adopted the PROCESS analysis developed by Hayes (2017) to check our hypotheses (*H2* and *H4*) associated with mediation. PROCESS analysis allows for a bootstrapping procedure to examine the conditional indirect effects, a more powerful procedure than Sobel's *z*-test to test for mediation effects (Zhao *et al.*, 2010). We set up 5,000 bootstrap samples as Preacher and Hayes (2008) suggested.

5. Results

We performed six independent models in a hierarchical structure for each model. For instance, for [SUPPLIER] and [CUSTOMER], we performed a two-step hierarchical regression where, in the first model, we only included control variables, and in the second, we included digital transformation constructs [DT_STRATEGY; BASE; FRONT_END]. In the case of green operations [PACKAGING; MANUFACTURING; PURCHASING], we regressed three hierarchical stages: only the control variables; digital transformation constructs; and green relationships constructs.

Finally, for [GREEN_PERF], we did a four-stage hierarchical procedure, including green operations in the last stage.

As shown in Table 2, all models were significant at $p < 0.001$, having significant R^2 changes ($p < 0.001$) in all stages in our hierarchical procedures. As a result, for the final step of each model we had: SUPPLIER ($F = 51.830$, $p = 0.000$), CUSTOMER ($F = 21.655$, $p = 0.000$), PACKAGING ($F = 19.774$, $p = 0.000$), MANUFACTURING ($F = 41.774$, $p = 0.000$), PURCHASING ($F = 101.002$, $p = 0.000$) and GREEN_PERF ($F = 34.994$, $p = 0.000$). Unstandardized coefficients are reported in Table 2 because all scales were standardized with *Z*-scores because they represent a standardized effect (Goldsby *et al.*, 2013).

Table 3 presents the estimates, standard errors, significance level and corresponding lower (LLCI) and upper level (ULCI) confidence intervals. We did not find any issues in the 95% confidence intervals because no bootstrapped indirect effects failed to be within the lower and upper levels. Finally, Table 4 summarizes the evaluation of the hypotheses.

Referring to mediation analysis (Table 3), we evaluated whether smart supply chain is an antecedent of GSCM. This means that the configuration of Smart Supply Chain dimensions (digital strategy, base technologies, and front-end technologies) is positively associated with higher GSCM

Table 2 Results of the regression analysis[a]

	Green relationships					Green operations			
Independent variables	**Supplier**		**Customer**			**Green packaging**		**Green manufacturing**	
GO_area	0.840 ($p = 0.000$)	0.377 ($p = 0.000$)	0.746 ($p = 0.000$)	0.396 ($p = 0.000$)	0.567 ($p = 0.000$)	0.322 ($p = 0.002$)	0.161	0.573 ($p = 0.000$)	0.369 ($p = 0.000$)
firm_size	0.126	0.131	0.010	−0.036	−0.106	−0.119	−0.145	0.183	0.192
DT_STRATEGY		0.436 ($p = 0.000$)		0.166 ($p = 0.009$)		0.179 ($p = 0.001$)	0.044		0.218 ($p = 0.000$)
BASE		−0.077		−0.047		0.036	0.063		−0.210 ($p = 0.005$)
FRONT_END		0.179 ($p = 0.005$)		0.341 ($p = 0.000$)		0.073	−0.029		0.251 ($p = 0.000$)
SUPPLIER							0.247 ($p = 0.000$)		
CUSTOMER							0.205 ($p = 0.000$)		
PACKAGING									
MANUFACTURING									
PURCHASING									
***F*-value**	52.674 ($p = 0.000$)	51.830 ($p = 0.000$)	25.858 ($p = 0.000$)	21.655 ($p = 0.000$)	19.899 ($p = 0.000$)	13.219 ($p = 0.000$)	19.774 ($p = 0.000$)	27.428 ($p = 0.000$)	18.192 ($p = 0.000$)
R^2	0.183	0.357	0.099	0.188	0.078	0.124	0.229	0.105	0.163
Adjusted R^2	0.180	0.350	0.095	0.180	0.074	0.115	0.218	0.101	0.154
Change in R^2	0.183 ($p = 0.000$)	0.174 ($p = 0.000$)	0.099 ($p = 0.000$)	0.089 ($p = 0.000$)	0.078 ($p = 0.000$)	0.046 ($p = 0.000$)	0.105 ($p = 0.000$)	0.105 ($p = 0.000$)	0.059 ($p = 0.000$)

Notes: [a]Unstandardized beta coefficients are reported as the main variables were standardized before regression. $n = 473$

(*continued*)

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Table 2

	Green operations							
Independent variables	**Green manufacturing**		**Green purchasing**				**Green performance**	
GO_area	0.142	0.687 (p = 0.000)	0.214 (p = 0.015)	−0.041	0.758 (p = 0.000)	0.373 (p = 0.000)	0.246 (p = 0.002)	0.216 (p = 0.005)
firm_size	0.146	0.327 (p = 0.002)	0.311 (p = 0.001)	0.243 (p = 0.001)	0.041	0.037	0.009	−0.024
DT_STRATEGY	0.011		0.376 (p = 0.000)	0.115 (p = 0.005)		0.336 (p = 0.000)	0.215 (p = 0.000)	0.204 (p = 0.000)
BASE	−0.170 (p = 0.008)		−0.0723	−0.024		0.038	0.061	0.089
FRONT_END	0.115		0.267 (p = 0.000)	0.129 (p = 0.009)		0.064	−0.009	−0.036
SUPPLIER	0.406 (p = 0.000)			0.561 (p = 0.000)			0.247 (p = 0.000)	0.132 (p = 0.014)
CUSTOMER	0.228 (p = 0.000)			0.139 (p = 0.000)			0.105 (p = 0.009)	0.048
PACKAGING								0.046
MANUFACTURING								0.167 (p = 0.000)
PURCHASING								0.058
***F*-value**	41.774 (p = 0.000)	42.851 (p = 0.000)	47.396 (p = 0.000)	101.002 (p = 0.000)	51.400 (p = 0.000)	44.426 (p = 0.000)	44.442 (p = 0.000)	34.994 (p = 0.000)
R^2	0.386	0.154	0.337	0.603	0.179	0.322	0.401	0.431
Adjusted R^2	0.377	0.151	0.330	0.597	0.176	0.315	0.392	0.419
Change in R^2	0.223 (p = 0.000)	0.154 (p = 0.000)	0.182 (p = 0.000)	0.267 (p = 0.000)	0.179 (p = 0.000)	0.143 (p = 0.000)	0.079 (p = 0.000)	0.030 (p = 0.000)

Table 3 Indirect effects (bootstrapping outcome)

Interactions (green relationships as mediators)	Bootstrap outcome Mean	SD	Sig.	95% confidence interval LLCI	ULCI	Total and direct effects	Sig.	Conclusion
DIGITAL TRANSFORMATION STRATEGY → SUPPLIER → PACKAGING	0.1394	0.0337	0.0000	0.0768	0.2105	Total effect	0.0000	Complete
DIGITAL TRANSFORMATION STRATEGY → CUSTOMER → PACKAGING	0.0680	0.0178	0.0000	0.0353	0.1050	Direct effect	0.057	Complete
FRONT-END TECHNOLOGIES → SUPPLIER → PACKAGING	0.1075	0.0231	0.0000	0.0663	0.1567	Total effect	0.0000	Complete
FRONT-END TECHNOLOGIES → CUSTOMER → PACKAGING	0.0779	0.0198	0.0000	0.0404	0.1186	Direct effect	0.3675	Complete
BASE TECHNOLOGIES → SUPPLIER → PACKAGING	0.1103	0.0242	0.0000	0.0674	0.1595	Total effect	0.0000	Complete
BASE TECHNOLOGIES → CUSTOMER → PACKAGING	0.0694	0.0184	0.0000	0.0354	0.1069	Direct effect	0.0968	Complete
DIGITAL TRANSFORMATION STRATEGY → SUPPLIER → MANUFACTURING	0.2362	0.0370	0.0000	0.1662	0.3112	Total effect	0.0000	Complete
DIGITAL TRANSFORMATION STRATEGY → CUSTOMER → MANUFACTURING	0.0729	0.0166	0.0000	0.0423	0.1069	Direct effect	0.6988	Complete
FRONT-END TECHNOLOGIES → SUPPLIER → MANUFACTURING	0.1528	0.0257	0.0000	0.1050	0.2071	Total effect	0.0000	Complete
FRONT-END TECHNOLOGIES → CUSTOMER → MANUFACTURING	0.0857	0.0196	0.0000	0.0496	0.1275	Direct effect	0.7642	Complete
BASE TECHNOLOGIES → SUPPLIER → MANUFACTURING	0.1707	0.0271	0.0000	0.1200	0.2257	Total effect	0.0000	Complete
BASE TECHNOLOGIES → CUSTOMER → MANUFACTURING	0.0813	0.0192	0.0000	0.0464	0.1214	Direct effect	0.1955	Complete
DIGITAL TRANSFORMATION STRATEGY→ SUPPLIER→ PURCHASING	0.3183	0.0356	0.0000	0.2506	0.3914	Total effect	0.0000	Partial
DIGITAL TRANSFORMATION STRATEGY → CUSTOMER → PURCHASING	0.0504	0.0136	0.0000	0.0263	0.0794	Direct effect	0.0002	Partial
FRONT-END TECHNOLOGIES → SUPPLIER → PURCHASING	0.2255	0.0319	0.0000	0.1656	0.2873	Total effect	0.0000	Partial
FRONT-END TECHNOLOGIES → CUSTOMER → PURCHASING	0.0476	0.0151	0.0004	0.0199	0.0796	Direct effect	0.0000	Partial
BASE TECHNOLOGIES→ SUPPLIER→ PURCHASING	0.2401	0.0315	0.0000	0.1795	0.3032	Total effect	0.0000	Partial
BASE TECHNOLOGIES → CUSTOMER → PURCHASING	0.0475	0.0141	0.0000	0.0221	0.0775	Direct effect	0.0001	Partial
Interactions (GSCM as mediators)	Mean	SD	Sig	LLCI	ULCI	Total and direct effects	Sig	Conclusion
DIGITAL STRATEGY → PACKAGING → GREEN PERFORMANCE	0.0223	0.0117	0.0472	0.0001	0.0463	Total effect	0.0000	Partial
DIGITAL STRATEGY → MANUFACTURING → GREEN PERFORMANCE	0.065	0.0179	0.0000	0.0326	0.1025			Partial
DIGITAL STRATEGY → PURCHASING → GREEN PERFORMANCE	0.0767	0.0239	0.0005	0.0318	0.1242	Direct effect	0.0000	Partial
BASE → PACKAGING → GREEN PERFORMANCE	0.0212	0.108	0.0312	0.0021	0.0444	Total effect	0.0000	Partial
BASE → MANUFACTURING → GREEN PERFORMANCE	0.0481	0.0152	0.0000	0.0220	0.0816			Partial
BASE → PURCHASING → GREEN PERFORMANCE	0.087	0.0214	0.0000	0.0475	0.1313	Direct effect	0.0000	Partial
FRONT-END → PACKAGING → GREEN PERFORMANCE	0.0222	0.0102	0.0126	0.0054	0.0455	Total effect	0.0000	Partial
FRONT-END → MANUFACTURING → GREEN PERFORMANCE	0.0558	0.0162	0.0000	0.0271	0.0905			Partial

(***continued***)

Table 3

Interactions (green relationships as mediators)	Bootstrap outcome Mean	SD	Sig.	95% confidence interval LLCI	ULCI	Total and direct effects	Sig.	Conclusion
FRONT-END → PURCHASING → GREEN PERFORMANCE	0.1030	0.0215	0.0000	0.0624	0.1465	Direct effect	0.0017	Partial
DIGITAL STRATEGY → SUPPLIER → GREEN PERFORMANCE	0.149	0.0335	0.0000	0.0881	0.218	Total effect	0.0000	Partial
DIGITAL STRATEGY → CUSTOMER → GREEN PERFORMANCE	0.0395	0.0137	0.0013	0.0141	0.0682	Direct effect	0.0000	Partial
BASE → SUPPLIER → GREEN PERFORMANCE	0.1448	0.0262	0.0000	0.0971	0.2004	Total effect	0.0000	Partial
BASE → CUSTOMER → GREEN PERFORMANCE	0.0337	0.0153	0.0078	0.0056	0.0658	Direct effect	0.0000	Partial
FRONT-END → SUPPLIER → GREEN PERFORMANCE	0.1445	0.0262	0.0000	0.0968	0.1989	Total effect	0.0000	Partial
FRONT-END → CUSTOMER → GREEN PERFORMANCE	0.0381	0.0164	0.0143	0.0061	0.0708	Direct effect	0.0019	Partial

Table 4 Hypotheses evaluation

Hypothesis	Outcome	Supported relationships
H1 **(Smart supply chain → Green performance)**	Partially supported (1 out of 3 relationships)	DT_STRATEGY ($B = 0.204$, $p = 0.000$)
H2a **(Smart supply chain → Green relationships)**	Partially supported (4 out of 6 relationships)	CUSTOMER: DT_STRATEGY ($B = 0.166$, $p = 0.009$) and FRONT_END ($B = 0.341$, $p = 0.000$) SUPPLIER: DT_STRATEGY ($B = 0.436$, $p = 0.000$) and FRONT_END ($B = 0.179$, $p = 0.005$)
H2b **(Smart supply chain → Green operations)**	Partially supported (2 out of 9 relationships)	PURCHASING: DT_STRATEGY ($B = 0.115$, $p = 0.005$) and FRONT_END ($B = 0.129$, $p = 0.009$)
H3 **(Green relationships → Green operations)**	Fully supported	SUPPLIER: PACKAGING ($B = 0.246$, $p = 0.000$), MANUFACTURING ($B = 0.409$, $p = 0.000$) and PURCHASING ($B = 0.561$, $p = 0.000$) CUSTOMER: PACKAGING ($B = 0.205$, $p = 0.000$), MANUFACTURING ($B = 0.228$, $p = 0.000$) and PURCHASING ($B = 0.139$, $p = 0.000$)
H4a **(Green operations → Green performance**	Partially supported (1 out of 3 relationships)	MANUFACTURING ($B = 0.167$, $p = 0.000$)
H4b **(Green relationships → Green performance)**	Partially supported (1 out of 2 relationships)	SUPPLIER ($B = 0.132$, $p = 0.014$)

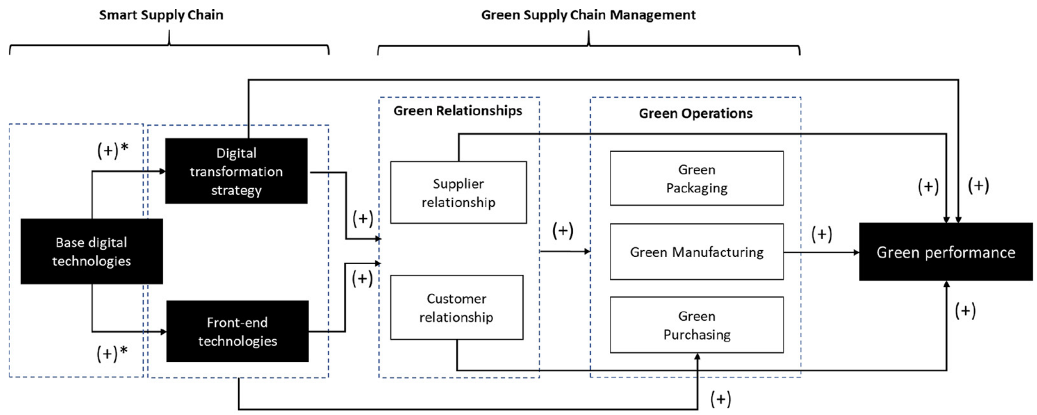
configuration and green performance levels. We found green relationships as mediators between smart supply chain (DT_STRATEGY, BASE and FRONT_END) and PACKAGING and MANUFACTURING. For PURCHASING, we have partial mediations because DT_STRATEGY, BASE and FRONT_END remained with a significant direct effect.

Furthermore, we evaluated whether the development of GSCM activities is positively associated with higher levels of green performance. We found partial mediations because the direct effect remained significant in the models for green operations (PACKAGING, MANUFACTURING and PURCHASING) as mediators between digital transformation and GREEN_PERF DT_STRATEGY, BASE and FRONT_END remained with a significative direct effect. Similarly, regarding green relationships (SUPPLIER and CUSTOMER) as mediators between digital transformation and GREEN_PERF, we found partial mediations because DT_STRATEGY, BASE and FRONT_END remained with a significant direct effect.

6. Discussion and theoretical contribution

Extant literature on SCM has focused either on the "smart" aspects of SCM by adopting digital technologies (Holmström *et al.*, 2019; Mak and Shen, 2021) or on the "green" aspects of the supply chain relations and operations to achieve higher green performance (Jayaraman *et al.*, 2007; Kumar *et al.*, 2021; Hohn and Durach, 2021). Our study offers an advance to both perspectives by providing a theoretical and empirical background on how both can be integrated. We show how the smart supply chain operates, in general, as a support for GSCM and is strongly associated, at the digital transformation layer, with higher levels of green performance. The configurational perspective allows us to explain that green performance is better achieved by the configuration of a Smart GSCM, which combines digital technologies with the external–internal alignment of green relationships and green operations. Our supported results and the additional discussions provided in this section are represented in Figure 2 which will be explained below.

Figure 2 Consolidated model for smart green supply chain management relationships



Note: *Post-hoc test to validate alternative explanation

We contribute to the literature of digital transformation in SCM with the definition of three different technological levels involved in implementing a smart supply chain. However, we did not find statistical evidence for the antecedent of Base Technologies on GSCM (Table 2). A possible reason is that Base Technologies are performed in the back-end of the implementation of the digital transformation strategy and the front-end technologies, being indirectly associated in the mediation path as represented in Table 3. We performed a post hoc regression analysis that validated this being base technologies positively associated to Digital Strategy (B = 0.417, p = 0.000; F-value = 94.743, p = 0.000; Adj. R^2 = 0.373) and to Front-end Technologies (B = 0.889, p = 0.000; F-value = 268.694, p = 0.000; Adj. R^2 = 0.630), as represented in the final consolidated model of Figure 2. Frank *et al.* (2019) argued that IoT, cloud computing, big data and AI provide the structure for implementing several digital applications, which in our study is represented by the other two layers (DT_STRATEGY and FRONT_END).

Previous studies have mainly considered only one of these different layers of smart supply chain, either by focusing on the strategic side of digital transformation in smart supply chain (Nasiri *et al.*, 2020) or by considering the technologies involved in our approach. We showed that three levels are necessary: the adoption of *base digital technologies* that enhance the level of the real-time data flow in the supply chain, a *strategy* that well defines the digitization intention and implementation of the company, and the adoption of specific *front-end technologies* for operational activities of the supply chain, like collaborative robotics, simulation, augmented reality and 3D printing (Frank *et al.*, 2019; Meindl *et al.*, 2021). The configuration of these three layers is more complex than simply a vertical hierarchic layer argued in our hypotheses, being this final configuration represented in Figure 2. We found that that digital transformation assumes a key antecedent role to support green activities entirely. Further extending extant research, we show how these three levels should be configured in an alignment between external–internal SCM activities since prior studies have only investigated the direct impact on sustainability and performance (Zhu *et al.*, 2013; Zhu and Sarkis, 2004). We demonstrated that digital technologies from the smart supply chain have a strong association with higher levels of green relationships, enhancing green relationships with suppliers and customers, which, in the end, results in higher levels of green performance. The adoption of digital tools allows, for instance, to track which green practices customers and suppliers are adopting. This will help better align the configuration of relationships with the configuration of internal operational activities (Flynn *et al.*, 2010). Therefore, our findings validate our general theoretical model, showing mechanisms of how digital technology effectively contributes to green performance, supporting that such a mechanism works through managing green relationships and establishing green operations.

The results and the abovementioned implications also make clear that digital transformation does not exclusively play a moderating role with GSCM (Narayanamurthy and Tortorella, 2021), but it acts as an antecedent of the entire GSCM, enabling the supply chain to become green oriented in its external-internal configuration alignment. Therefore, rather than only being two independent trends that can create synergistic results as sometimes suggested (Birkel and Müller, 2020), the success of GSCM will depend on the adoption of a smart supply chain based on digital technologies. Our findings challenge the operations management literature to not consider digital transformation as the final goal and sufficient to achieve green performance (Birkel and Müller, 2020; Kumar *et al.*, 2021; Pasi *et al.*, 2020). Although we show in our results that digital transformation strategy directly affects green performance (Figure 2), there is much more "in the middle of the way." We show that smart supply chain, which is based on digital transformation, effectively enhances green performance without establishing the complete GSCM practices that mediate such effects. Digital transformation, consequently, is not a means to enhance performance (Erboz *et al.*, 2021) but the antecedent that better grounds the business configuration between the external and internal green activities that results in better performance. Hence, external and internal GSCM practices must be better integrate (Flynn *et al.*, 2010), also in the context of GSCM.

Furthermore, our results show that digital transformation has a key role in one specific dimension of green operations, which is green purchasing. Purchasing is an internal operation of the configurational structure of the GSCM, but it has deep connections with the external market. While green relationships mediate the relationship between smart supply chain and green operations, purchasing can be an activity directly focused on the market and suppliers without depending on specific long-term relationships (Müller *et al.*, 2020). Therefore, green purchasing requires direct support of digital technologies to identify better purchase options quickly. Buying inputs for green requirements include ISO 14001 standards or green design concepts. Market information and digital tools can help track these requirements and localize good suppliers that meet all these conditions, helping to enhance green purchasing capacity (Hsu *et al.*, 2016; Laari *et al.*, 2016). Therefore, purchasing and buyer–supplier relationships are some of the most important internal SCM activities that directly benefit from the digital transformation for smart supply chain (Müller *et al.*, 2020).

We also expand the view of smart supply chain and its contribution to green aspects by including the data-related technology perspective, comprehended by the *digital transformation strategy* and the *base digital technologies* constructs. Most of the studies on smart supply chain have focused on this data-driven perspective of digital transformation (Kumar *et al.*, 2021; Nasiri *et al.*, 2020; Pasi *et al.*, 2020). We advance a further step by considering the *front-end technologies*, which involve human–machine interaction in the supply chain operational activities (Frank *et al.*, 2019). Meindl *et al.* (2021) provided an extensive literature review on smart supply chain and showed that the workers' perspective is little explored in this topic. Dornelles *et al.* (2022) investigated the smart working role of digital technologies in enabling workers. However, their study is restricted to the manufacturing domain, while this view could be expanded to the supply chain field oriented to green practices. In this sense, we show that role of front-end technologies is important for GSCM can support several supply operations. For instance, simulation tools help better define suppliers' demand and reduce logistics movements that can increase emissions and transportation impacts in shipping or balance loads and energy consumption (Birkel and Müller, 2020). It can also help workers to improve decision-making regarding supply certification or workers working with virtual machine vision to identify potential recycling wastes from the operations, as just some examples of smart working tools in this field (Dornelles *et al.*, 2022).

Regarding the configuration between green relationships and green operations, the configurational view allows us to validate the association that the external green relationships have with internal green operations as an antecedent. However, our results also expanded this view by showing that managing green relationships with customers and suppliers also directly affects green performance, not only through the mediation of internal green operations. In other words, a company that manages supplier and customer relationships but does not focus on internal green operations can even though obtain better green performance than without such practices, and the same is true for internal green operations. However, when companies configure the GSCM business in an integrative perspective with an alignment of external and internal practices, the achievement is even higher in green performance. Prior studies have considered other views like the perspective of resources necessary following the resource-based view (Gavronski *et al.*, 2011; Li *et al.*, 2020) or how to build relational aspects to support such green activities (Parmigiani *et al.*, 2011). Our study brings an additional perspective that is necessary to develop Smart GSCM.

7. Conclusion

Our study consolidates a theoretical model through empirical validation of Smart GSCM. Using the configurational view, we show the relationships between smart supply chain and GSCM dimensions, congregating them under the framework of a Smart GSCM that can contribute to green performance through digital transformation. We show that the smart supply chain dimension is configured in three layers. Two of them are central for SCM: Digital transformation strategy and front-end technologies, while base technologies (IoT, cloud computing, big data, AI and blockchain) contribute to support digital transformation. Thus, this paper enhances the understanding of how the digital transformation dimensions contribute to creating a Smart GSCM (Frank *et al.*, 2019; Meindl *et al.*, 2021). Furthermore, the external dimension of GSCM (customer and supplier green relationship management) and the internal dimension (green operations in manufacturing, packaging and purchasing) contribute to green performance. This specifies findings of extant literature (Zhu *et al.*, 2013) regarding a configurational view of external and internal dimensions of SCM. Hence, we present a holistic understanding of the different dimensions and mechanisms that operate in Smart GSCM. This holistic understanding combines digital technologies (Holmström *et al.*, 2019; Mak and Shen, 2021) and their interplay with supply chain relations and operations (Jayaraman *et al.*, 2007; Kumar *et al.*, 2021; Hohn and Durach, 2021) in a single research context, investigating how to achieve higher green performance.

7.1 Implications for practice

This study contributes to the sustainable development goals proposed by the 2030 Agenda for Sustainable Development of the United Nations[1]. From the 17 goals proposed in the 2030 Agenda, our study is strongly aligned with Goal 12: Ensure sustainable consumption and production patterns. This goal is concerned with adopting practices that can help reduce the carbon and material footprint of companies and, consequently, nations. Our study shows that when companies configure a Smart SCM, they can improve several green performance metrics that contribute to this goal, such as increasing material recycling, reducing emissions and reducing the use of resources, including hazardous and environmentally harmful materials.

For managerial practice, this paper highlights the relationships between the smart supply chain and GSCM, leading to Smart GSCM. Companies that aim to increase green performance need to integrate external and internal GSCM practices, which directly affect green performance. At the same time, companies can apply digital technologies to achieve a higher degree of development of the configurational aspects of GSCM. Furthermore, pursuing a smart supply chain is not sufficient to achieve green performance, but the combination with GSCM is a vital factor in achieving a Smart GSCM. We thus recommend pursuing joint rather than single technological and operational approaches to increase green performance. The configurational view calls attention to how managers should integrate these three perspectives of SCM: digital transformation, external relationships and internal operations. Practitioners can use our model to guide the supply chain transition to smart GSCM through the adoption of base technologies that can later be combined with a digital transformation strategy and front-end technologies to support the configurational green supply chain structure. Using such a configurational Smart GSCM model combined with a correct assessment of digital technology investments can help establish a digital transformation journey in the supply chain (Almeida *et al.*, 2022).

7.2 Limitations and future research

Our study has the limitation that it considers single responses from the companies. Thus, the study could be improved by combining responses and performance data from multitier supplier chain settings, including several operations and supply chain processes interconnected. Therefore, our study is the first step to larger research with more GSCM stakeholders. Further limitations include that the results are based on cross-sectional data. Hence, a long-term investigation presents a promising future research avenue. GSCM and smart supply chain represent emerging concepts that can be expected to develop significantly in the next years. Such an approach could include how smart supply chain is implemented across several supply chain tiers and how this process evolves over time.

Moreover, digital technologies can support supplier integration in the product development process (Ayala *et al.*, 2020) or avoid glitches when such integration happens (Merminod *et al.*, 2021), which can help develop green products aligned with the GSCM system of the firm. Future studies could advance in this direction of research. Finally, although most firms are active in multinational settings and engage in global supply chains, the study focuses on firms from or active in Brazil. Prior research in this market has shown that companies are less open to external collaboration with stakeholders due to industrial uncertainties (Frank *et al.*, 2021). Also, investments in technologies are not well aligned with the expected innovation outputs compared to developed countries (Frank *et al.*, 2016). In another study, Dalenogare *et al.* (2018) showed that Brazilian companies that invest in digital technologies have not as high priority sustainable goals as European countries. These are some differences that can produce different results when compared to companies from developed countries in the GSCM domain. In such countries, issues like open innovation with suppliers, technology investment to increase innovation outputs and expected benefits to achieving sustainable goals tend to be more consolidated. Thus, the effects of the statistical inferences found in this study should be considered limited to the national context. Future studies should expand such findings to global supply chains where these practices are more consolidated. Moreover, academics could devote effort to analyzing differences in digital and green practices between developed and emerging countries to find the gaps and show the main differences. This would be helpful to understand better the potential tensions, and ways companies in both types of contexts differentiate. Based on this, research policies can be proposed to reduce such gaps in managerial practices that can help achieve global sustainable goals.

Note

1. https://sdgs.un.org/goals

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Appendix 1

Table A1 Literature review on smart supply chain and green supply chain management's relationship to performance[a]

Authors	Journal	Proposal	Contributions	Limitations
Belhadi *et al.* (2021)	*Supply Chain Management*	Proposed a sustainable Industry 4.0 model, showing how digital business transformation could impact sustainable supply chain performance by using a circular business model	Showed the moderation role of digital business transformation between circular business model impact and sustainable performance	As the article looked at the dynamic capabilities of Industry 4.0 and digital business transformation, the article did not address the different technologies that companies can adopt. Furthermore, the article focused on the circular economy rather than internal and external supply chain practices, which does not reflect the main sustainable operations of a supply chain
Machado *et al.* (2021)	*Sustainability (Switzerland)*	Presented the main barriers and enablers regarding the digital transformation in the green supply chain	Presented a framework that integrates the digital transformation and green supply chain for MSMEs, differentiating companies into two groups (micro, small and medium). The propositions and the framework support the adoption of digital transformation for the green supply chain	The article presented a narrow view of the use of technologies and sustainability. The article highlighted the issue of cybersecurity issues and alternative use of energy and resources. Even though barriers related to sustainability, technologies and integration with customers and suppliers are highlighted in the article, it was not the central theme. The paper lacks defining elements for these constructs
Caldarelli *et al.* (2020)	*Sustainability (Switzerland)*	Investigated how blockchain can improve the effectiveness of organizations and the sustainable supply chain	Presented how blockchain technology affects technology, structure, culture, discovery, monitoring, adaptation and trust	The article focused on using a base technology (blockchain) in the context of green supply chains being limited to a single variable (technology) analysis
Varriale *et al.* (2021)	*Sustainability (Switzerland)*	Investigated how blockchain, smart contracts, IoT and RFID could evaluate sustainability aspects	Digital technologies are responsible for reducing waste. Blockchain is crucial to track transactions and improve transparency alongside the supply chain ties to lead companies to performance	The article focused on using three digital transformation technologies (blockchain, IoT, RFID) for order management in green supply chains through a simulation. However, the article did not explain the main internal and external activities that manufacturing companies should invest in to achieve their results. There is a lack of how to align sustainable operations and base technologies in this study
Tseng *et al.* (2021)	*Sustainability (Switzerland)*	Analyzed the main aspects and criteria to understand how digitalization could improve sustainable supply chain competitiveness	A total of four aspects are crucial to green supply chain management: digital platform effectiveness, digital communication belonging to the supply chain digitalization perspective, labor conditions and manufacturing processes	The article addressed the importance of digital platforms, digital communication, real-time updated inventories and information transparency but did not focus on technological and strategic aspects. In addition, the article highlighted the importance of collaboration between suppliers and clean production, but it is

(*continued*)

Table A1

Authors	Journal	Proposal	Contributions	Limitations
				limited to only internal practices related to production. Furthermore, it did not bring an integrated view of the use of digital technologies and green practices in supply chains to achieve the desired environmental performance goals
Martín-Gómez *et al.* (2019)	*Resources, Conservation and Recycling*	Developed a framework to create an adaptive and integrated sustainable supply chain management for a sustainable supply chain based on a circular economy	The study identified the main requirements to reach green supply chain management. It creates a conceptual framework that merges circular economy and GSCM by developing a holonic framework to show the intersection between GSCM and Industry 4.0	The proposed framework showed vertical and horizontal synergy in using cyber-physical systems with a focus on aspects of reverse logistics and manufacturing in the green supply chain part. However, the framework did not analyze the use of different technologies focusing on environmental development as the article focused on the exchange of supply chain resources to improve the relationships with partners
Zekhnini *et al.* (2021)	*International Journal of Production Research*	Reviewed the literature to understand the intersection between sustainable green supply chain, digital transformation and sustainable performance	The study presented a roadmap that shows the digital transformation technologies and performance, helping to develop research related to green, lean and digital aspects of supply chain performance. This roadmap brought an integrating perspective on digital SCM, sustainability improvement and performance	The article brought a nonintegrated view of the use of technologies for green supply chain practices and improvements in sustainability
Hohn and Durach (2021)	*International Journal of Operations and Production Management*	Studied how AM could impact social practices in the global supply chain in the apparel industry by analyzing how AM could be implemented in this industry and how AM impacts social sustainability	The use of AM to rethink how the clothing industry could add value to their supply chain, so they developed nine propositions to be tested based on future research	The article focused on AM without analyzing the digital transformation strategy, the adoption of base technologies and the adoption of other front-end technologies. The study analyzes the impact on supply chain governance rather than environmental impacts
Gong *et al.* (2022)	*Industrial Marketing Management*	Presented an overview of the main challenging factors related to marine plastic debris management; discussed how blockchain technologies could support this management and studied the advantages of adopting blockchain technologies	The use of blockchain, digital wallets and smart contracts can improve the transparency of marine debris's global circular supply chain, creating a closed-loop system. Companies should invest in the following aspects: formalization of the recycling profession, creation of economic benefits, global cooperation, a digital currency system, transaction security and a transparent and efficient recycling chain	The article addressed the use of technologies and sustainability. However, the article focused on the use of blockchain in the circular economy and recycling. Therefore, the focus was on improving supplier relationships to close the loop and not on the synergy among internal and external supply chain practices
Saberi *et al.* (2019)	*International Journal of Production Research*	Reviewed the literature to understand the role of blockchain technologies on sustainable supply chains	A total of four barriers were highlighted related to the adoption of blockchains in their supply chains: interorganization,	The article brought a broad view of the use of blockchain for suppliers, manufacturing processes, distributors and consumers,

(*continued*)

Table A1

Authors	Journal	Proposal	Contributions	Limitations
			intraorganizational, technical and externals	showing the importance of green manufacturing, green purchasing and green relationship. In addition, the study presented how blockchain can support the green supply chain. However, even bringing some strategic aspects, it did not address the use of other digital technologies or the environment's impact
Cole *et al.* (2019)	*Supply Chain Management*	Presented the implication of adopting blockchain technology on operations management and supply chain management, especially green supply chain management	The study showed that blockchain is important to social sustainability, mainly related to labor-intensive and modern slavery	The article addressed the use of blockchain in supply chains focusing on customer and supplier relationships. The core idea was to create smart contracts to help with inventory control, but the green procurement process can be better detailed and supported by internal manufacturing and packaging processes. The text's topic of sustainability was secondary, focusing on economic performance rather than environmental performance
Caiado *et al.* (2022)	*Sustainability (Switzerland)*	Proposed a framework to add sustainable Industry 4.0 to the supply chain aligned with the Sustainable Development Goals of the United Nations (SDGs)	Discussed opportunities, challenges and benefits of achieving digitalization on GSCM for sustainable development	The article showed a vision of the use of multiple technologies with challenges between digital technologies and the environment and presents the benefits of adopting technologies for environmental aspects focusing on the SDGs. The paper lacks a focus on the strategic side of digital transformation implementation
Oguntegbe *et al.* (2022)	*TQM Journal*	Analyzed the adoption of blockchain on social practices in supply chain management	Proposed new responsible management practices to promote GSCM using blockchain technology	The article focused on using digital technologies rather than analyzing the adoption of technologies with the strategic use of technologies. The green supply chain management part focused on the external aspects of strategic collaborations but not on the internal parts that the company can perform, lacking an integrative view of both practices (internal and external)
Kumar *et al.* (2022)	*International Journal of Productivity and Performance Management*	Developed an I4.0-based virtual organization to coordinate a sustainable supply chain	Proposed a digital transformation model for improving green supply chain management	The article analyzed the use of different technologies in the manufacturing process, focusing on cost reduction and sustainable innovation. However, the article did not present a strategic view of the use of technology. Furthermore, the environmental aspect was much more related to eco-friendly issues than the

(***continued***)

Table A1

Authors	Journal	Proposal	Contributions	Limitations
				external and external green aspects of the GSCM
Bechtsis *et al.* (2021)	*International Journal of Production Research*	Developed a digital, resilient and sustainable supply chain framework	Proposed a data-driven technologies framework that could create a resilient, digital and sustainable supply chain based on challenges and motivations, including a focus on social sustainability	Technological aspects were related to data sharing and data monetization models rather than technologies
Jabbour *et al.* (2020)	*Science of the Total Environment*	Reviewed the role of big data technologies on sustainable supply chain management	Four lessons on big data-driven supply chain management and its possible applications on triple bottom line dimensions	The article focused on using big data technology instead of integrating other technologies and a digital transformation strategy. Furthermore, the article did not clearly show the relationship between green relationships and green operations
Martín-Gómez *et al.* (2021)	*Applied Sciences (Switzerland)*	Analyzed the adoption of CPS in manufacturing systems based on the sustainable and circular value chain	Proposed a CPS framework/roadmap to model the manufacturing system to improve the green value chain	The article focused on aspects of green manufacturing and circular economy and brought up issues of technological transformation. The focus of the article was related to sustainable consumption using technologies. Therefore, the article did not address a configurational approach for these practices and technologies
Liu *et al.* (2021)	*Technological and Economic Development of Economy*	Presented blockchain technology to improve the global supply chain and its effects on sustainable supply chains	A total of four categories of barriers to adopting blockchain were highlighted to present an interconnection between the barriers to technology adoption in sustainable supply chain management	The article looked at the use of blockchain technology rather than looking at other technologies. The authors analyzed the use of technology in supply chain transformation but did not distinguish between internal and external aspects of the green supply chain. The article did not focus on environmental performance
Ebinger and Omondi (2020).	*Sustainability (Switzerland)*	Discussed the role of digital transformation on the green supply chain based on sustainable supply chain transparency (SSCT)	Proposed data-driven technology framework that can potentialize the results from SSCT, showing how digital transformation can be approached on a sustainable supply chain	The article showed different technologies for traceability and tracking, cooperation and partners selection, governance, strategic and operational risk assessment in green supply chains. Therefore, the authors neither look at the internal and external aspects of the green supply chain management nor the environmental impact of the smart green supply chain
Sislian, and Jaegler (2022)	*Business Strategy and the Environment*	Analyzed the main contribution of ERP modules to mitigate the blockchain issues to improve sustainable corporate performance by integrating the supply chain	Proposed seven recommendations for the integration between blockchain technologies and ERP modules benefit companies to achieve their desired economic performance goals by integrating the supply chain	The article analyzed the use of blockchain and how it impacts the information process and supply chains. That is, it did not analyze the use of other technologies. In addition, it did not address the use of technologies in supply chains to

(***continued***)

Table A1

Authors	Journal	Proposal	Contributions	Limitations
				achieve environmental sustainability
Edwin Cheng *et al.* (2021)	*International Journal of Production Research*	Analyzed the relationship between big data analytics (BDA) capabilities, circular economy and sustainable supply chain (SSC) flexibility	The study showed that BDA capabilities are related to circular economy practices and sustainable supply chain flexibility. However, BDA is not associated with SSC performance	The article analyzed the capabilities of using Big Data Analytics instead of analyzing the digital transformation strategy and use of front-end technologies. Furthermore, the article focused on using circular economy concepts that include green manufacturing issues but do not include green packaging or green purchasing. Furthermore, the article focuses on supply chain flexibility, which analyzes flexibility with green suppliers but does not analyze consumers' relationships
Gunduz *et al.* (2021)	*Computers and Industrial Engineering*	Proposed a new methodology that merges the best-worst method (BWM) and quality function deployment (QFD), which analyze the level of smartness and sustainability of the supply chain management	The study presented that big data solutions for ship information management and automation and system digitalization are critical engineering characteristics	The article used technologies focusing on data analysis technologies but did not specifically address the digital transformation strategy. In addition, the article brought sustainability indicators, which are present in our article as well. The article focused heavily on suppliers, their selection, and manufacturing aspects of agility, flexibility and resiliency but did not focus on specific internal operations like packaging and purchasing practices
Michel-Villarreal *et al.* (2021)	*Sustainability (Switzerland)*	Explored the potential benefits of the adoption of digital transformation technologies for creating a sustainable short food supply chain	Proposed that low-cost technologies can support flexibility, collaboration and agility of sustainable short food supply chain	The article focused on how low-cost digital technologies can support flexibility, collaboration, visibility and agility. The article did not look at several more expensive technologies that can be front-end technologies and how they influence internal and external aspects of green supply chains. Furthermore, the article did not show the impact on environmental performance
Del Giudice *et al.* (2020)	*International Journal of Logistics Management*	Proposed a conceptual model to understand the relationship between circular economy and firm performance and the moderating role of a big data-driven supply chain	The big data supply chain played a moderator role between the circular economy and firm performance (economic, social and environmental), supporting the decision-making process	The article focuses on the moderating role of big data between three circular economy constructs related to manufacturing, human resource relationships and management, and environmental performance. In other words, the article did not address the use of a digital strategy or the use of technologies. In addition, it did not bring the

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Table A1

Authors	Journal	Proposal	Contributions	Limitations
				aspects of green relationships and green operations
Lee (2021a)	*Sustainability (Switzerland)*	Proposed a supply chain framework related to the relationship between sustainable supply chain, smart supply chain integration and firm performance	The study showed that sustainable SCM influences the adoption of a digital supply chain, focusing on supply chain integration	The article focused on the digital integration of the supply chain rather than analyzing a digital strategy and the use of technologies. Furthermore, the article used operational performance rather than environmental performance as an output
Benzidia *et al.* (2021)	*Technological Forecasting and Social Change*	Extended the role of big data analytics and artificial intelligence (BDA-AI) and digital learning in the green supply chain process	The study presented that BDA-AI is associated with the environmental integration process and supply chain collaboration. In addition, the study showed the moderating role of digital learning between BDA-AI and green supply chain collaboration	The article focused on using two base technologies (big data analytics and artificial intelligence). Therefore, the article does not address the issue of strategies or the use of front-end technologies. The article approached the company's internal development as a vision of green process integration instead of analyzing purchasing, manufacturing and packaging processes. In addition, the article looked at collaboration with a focus on suppliers. That is, it does not focus on customer relationships
Nayal *et al.* (2022)	*Business Strategy and the Environment*	Examined the effect of supply chain collaboration and coordination (SCC), sustainable development strategy (SDS), digital transformation (DIT) and collaborative advantages (COA) on sustainable supply chain firm performance (SSCFP)	The study showed that digital transformation is associated with firm performance, and sustainable strategy is related to digital transformation	The article used a more strategic construct of digital transformation but did not use more technological constructs. In addition, the performance variable mixed environmental and operational aspects, which makes it difficult to analyze the impact on environmental aspects because there is a conceptually mixed construct. Again, supply chain constructs focused on strategic and supplier aspects rather than analyzing both external and internal operations
Lee (2021 b)	*Sustainability (Switzerland)*	Proposed a real-time framework for fashion supply chains	The study showed the integration between AI and 3D simulation in the fashion industry, digitalizing this industry and saving time and money. In addition, AI supports manufacturing machine design. Based on this, the author discussed a sustainable real-time fashion system concerning a sustainable supply chain	The article analyzed the use of various technologies for manufacturing and customer relationships. However, it did not use most base technologies or digital strategies, lacking clarity in digital transformation phenomena. The article focused on the consumer relationship rather than analyzing both the supplier and the consumer relationship. In addition, the article brought manufacturing aspects separately and purchasing

(***continued***)

Table A1

Authors	Journal	Proposal	Contributions	Limitations
				aspects with the consumer issue but did not address packaging aspects

Notes: [a]Search terms (Scopus database): "digital transformation" AND "supply chain" AND "sustainability" (OR) "digital" AND "green supply chain" (OR) "digital" AND "sustainable supply chain." Initially, our search filters identified 18, 9 and 49 articles, respectively. During our identification phase, we removed duplicates, resulting in 69 articles. After removing the duplicates, we started the screening phase (preliminary reading), resulting in 59 articles, after the final complete reading resulted in 28 articles

Appendix 2. Questionnaire

Questionnaire items to assess Digital Transformation Strategy (DT_STRATEGY) (Adapted from Nasiri *et al.*, 2020) *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.077; CFI = 0.991; AVE = 0.68; Cronbach = 0.91; CR = 0.99. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H1*, *H2a* and *H2b*.)

a. We aim to digitalize everything possible in the supply chain (0.81).
b. We aim to collect large amounts of data from different sources in the supply chain (0.77).
c. We aim to create a stronger communication network between different sectors of the supply chain with digital technologies (0.85).
d. We aim to exchange information in the supply chain with digitalization (0.88).
e. We aim to improve the interface with customers with digitization efficiently (0.81).

Questionnaire items to assess Base Digital Technologies (BASE) (Adapted from Frank *et al.*, 2019; Meindl *et al.*, 2021). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. Cronbach = 0.87; CR = 0.99. This construct was developed as a formative approach (sum of values).* (We used these questions to measure the following hypotheses: *H1*, *H2a* and *H2b*)

a. We use Internet of Things in our supply chain processes.
b. We use cloud computing in our supply chain processes.
c. We use Big Data Analytics in our company processes and in the supply chain.
d. We use artificial intelligence in supply chain processes.
e. We use blockchain in the supply chain processes.

Questionnaire items to assess Front-End Technologies (FRONT_END) (Adapted from Frank *et al.*, 2019). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. Cronbach = 0.84; CR = 0.98. This construct was developed as formative approach (sum of values).* (We used these questions to measure the following hypotheses: *H1*, *H2a* and *H2b*.)

a. We use collaborative robotics in our company processes and in the supply chain.
b. We use computer simulation in supply chain processes.
c. We use augmented reality in supply chain processes.
d. We use 3D printing in supply chain processes.

Questionnaire items to assess Green Supplier Relationship (SUPPLIER) (Adapted from Laari *et al.*, 2016). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.065; CFI = 0.99; AVE = 0.63; Cronbach = 0.87; CR = 0.99. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H2a*, *H3* and *H4a*.)

a. Our company cooperates with suppliers to take environmental issues into account in product design (0.79).
b. Our company develops input logistics with suppliers to be more environmentally friendly (0.85).
c. Our company and our suppliers have a clear mutual understanding of responsibilities in environmental issues (0.72).
d. Our company prefers suppliers that have an environmental management system (0.80).

Questionnaire items to assess Green Customer Relationship (CUSTOMER) (Adapted from Laari *et al.*, 2016). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.075; CFI = 0.99; AVE = 0.68; Cronbach = 0.87; CR = 0.99; Cronbach = 0.91; CR = 0.99. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H2a*, *H3* and *H4a*.)

a. Our company works together with customers to take environmental issues into account in product design (0.82).
b. Our company and our customers have a clear and mutual understanding of responsibilities in environmental issues (0.86).
c. Our customers have asked us for information on our environmental compliance (0.81).
d. Our customers have demanded our company to ensure sustainable practices of our suppliers (0.86).
e. Our customers have demanded us to implement an environmental management system (e.g. ISO 14000, EMAS) (0.77).

Questionnaire items to assess Green Packaging (PACKAGING) (Adapted from Ninlawan *et al.*, 2010; Hsu *et al.*, 2016). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.040; CFI = 0.99; AVE = 0.46; Cronbach = 0.76; CR = 0.98. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H2b*, *H3* and *H4b*.)

a. Our company packaging is reusable (0.65).
b. Our company's packaging uses as few materials as possible (0.48).
c. Our company encourages the use of reusable packaging (0.86).

d. Our company promotes packaging recycling and reuse programs (0.67).

Questionnaire items to assess Green Manufacturing (MANUFACTURING) (Adapted from Hsu *et al.*, 2016). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.096; CFI = 0.957; AVE = 0.45; Cronbach = 0.71; CR = 0.98. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H2b*, *H3* and *H4b*.)

a. Our company assesses the environmental impact to develop/improve products (0.74).
b. Our company develops products with recyclable raw material (0.50).
c. Our company develops products with lowest consumption of resources (0.68).
d. Our company develops products with low impact on the environment (0.73).
e. Our company develops products with a high life span (0.34).

Questionnaire items to assess Green Purchasing (PURCHASING) (Adapted from Hsu *et al.*, 2016; Green *et al.*, 2012; Zhu *et al.*, 2008). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.038; CFI = 0.99; AVE = 0.50; Cronbach = 0.79; CR = 0.98. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H2b*, *H3* and *H4b*.)

a. Our company purchases based on environmental specifications established by product design (0.75).
b. Our purchasing process is carried out with ISO 14001 certified partners (0.59).
c. Our purchasing process follows procedures that minimize environmental impact (0.76).
d. Our purchasing process follows product labeling standards to minimize environmental impact (0.71).

Questionnaire items to assess Green Performance (GREEN_PERF) (Adapted from Cousins *et al.*, 2019; Zhu *et al.*, 2008). *Concordance Likert scale: 1 – strongly disagree to 5 – strongly agree. RMSEA = 0.085; CFI = 0.99; AVE = 0.57; Cronbach = 0.84; CR = 0.98. Factor loadings are shown in parentheses.* (We used these questions to measure the following hypotheses: *H1*, *H4a* and *H4b*.)

a. Our company has increased material recycling over the past three years (0.75).
b. Our company has reduced emissions over the past three years (0.73).
c. Our company has reduced use/waste of resources over the past three years (0.79).
d. Our company has decreased its use of hazardous/ environmentally harmful materials in the last three years (0.76).

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Appendix 3

Table A2 Bivariate correlation matrix

Independent variables		1	2	3	4	5	6	7	8	9	10	11
1	Control_GO	–										
2	Firm_size	0.189 (p = 0.000)	–									
3	DT_STRATEGY	0.459 (p = 0.000)	0.067	–								
4	BASE TECHNOLOGIES	0.419 (p = 0.000)	0.166 (p = 0.000)	0.559 (p = 0.000)	–							
5	FRONT_END TECHNOLOGIES	0.358 (p = 0.000)	0.143 (p = 0.002)	0.409 (p = 0.000)	0.796 (p = 0.000)	–						
6	SUPPLIER RELATIONSHIP	0.425 (p = 0.000)	0.130 (p = 0.005)	0.549 (p = 0.000)	0.365 (p = 0.000)	0.365 (p = 0.000)	–					
7	CUSTOMER RELATIONSHIP	0.315 (p = 0.000)	0.063	0.311 (p = 0.000)	0.370 (p = 0.000)	0.370 (p = 0.000)	0.545 (p = 0.000)	–				
8	GREEN PACKING	0.276 (p = 0.000)	0.010	0.301 (p = 0.000)	0.226 (p = 0.000)	0.226 (p = 0.000)	0.425 (p = 0.000)	0.387 (p = 0.000)	–			
9	GREEN MANUFACTURING	0.314 (p = 0.000)	0.135 (p = 0.003)	0.305 (p = 0.000)	0.261 (p = 0.000)	0.261 (p = 0.000)	0.572 (p = 0.000)	0.484 (p = 0.000)	0.420 (p = 0.000)	–		
10	GREEN PURCHASING	0.370 (p = 0.000)	0.200 (p = 0.000)	0.503 (p = 0.000)	0.420 (p = 0.000)	0.420 (p = 0.000)	0.742 (p = 0.000)	0.520 (p = 0.000)	0.437 (p = 0.000)	0.552 (p = 0.000)	–	
11	GREEN_PERF	0.423 (p = 0.000)	0.098 (p = 0.033)	0.520 (p = 0.000)	0.332 (p = 0.000)	0.332 (p = 0.000)	0.548 (p = 0.000)	0.401 (p = 0.000)	0.356 (p = 0.000)	0.467 (p = 0.000)	0.505 (p = 0.000)	–
	Mean	0.514	0.784	3.971	11.934	9.367	3.733	3.213	3.757	3.768	3.677	4.024
	SD	0.500	0.412	0.924	4.442	4.551	1.012	1.188	0.998	0.959	0.999	0.904
	Skewness	−0.055	−1.387	−0.932	−0.209	0.322	−0.743	−0.229	−0.938	−1.120	−0.673	−1.062
	Kurtosis	−2.005	−0.076	0.633	−0.769	−0.759	−0.346	−1.160	0.245	1.341	−0.292	1.091

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