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Circular supply chain orchestration to overcome Circular Economy challenges: An empirical investigation in the textile and fashion industries

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ABSTRACT

The transition towards Circular Economy is needed, all the more in industries with a harmful environmental impact such as the textile and fashion ones. This transformation, however, presents several challenges. While these challenges have been widely investigated in literature, solutions to overcome them have received much less attention to date. Practices and strategies proposed by the literature are still largely fragmented and not interpreted through an overarching theory, which prevents the understanding of how circular supply chains should be managed and coordinated. Therefore, this paper proposes a circular supply chain orchestration approach to understand responses to Circular Economy adoption barriers in the textile and fashion supply chains. A multiple case study has been carried out in the Prato (Italy) regenerated wool district, which has been practicing Circular Economy for more than a century. The paper contributes to knowledge accumulation on circular supply chain orchestration by integrating the resource orchestration, supply chain orchestration and Circular Economy streams. It adopts this perspective as a theoretical lens to analyse responses to challenges and, in particular, to operationalize the general orchestration mechanisms pointed out in the extant literature. Our study also provides support to managers in the textile supply chain to design challenge-response orchestration mechanisms in the move towards Circular Economy.

1. Introduction

The textile and fashion industries are among the most polluting ones (Jia et al., 2020): they globally consume almost 100 million tons of non-renewable resources each year; 100 billion m^3 of water, and emit more than 1 billion tons of CO_2. With the increase of fast fashion, in the last 15 years apparel production has nearly doubled, while the life of each cloth has been reduced (Ellen MacArthur Foundation, 2017). Thus, great environmental benefits would be associated to a transition of the textile industry towards a Circular Economy (CE), which decouples economic growth from environmental losses and resource extraction, replacing the end-of-life of textiles with their reuse and recycling (Bukhari et al., 2018; Sandin and Peters, 2018).

Despite an ever-growing interest of CE in the textile and fashion industries, its implementation in companies and supply chains is still far from being accomplished (Shirvanimoghaddam et al., 2020; Vehmas et al., 2018) due to several challenges and barriers (Jia et al., 2020; Kazancoglu et al., 2020). While these barriers have been widely investigated in literature, solutions to overcome them have received much less attention to date: literature proposed some practices and strategies, but they are still largely fragmented and not interpreted through an overarching theory, which could help understanding how circular supply chains should be managed and coordinated to overcome challenges. On the other hand, the resource orchestration view has emerged recently as a promising area of research, but the literature adopting this approach to circular supply chains is still at a nascent stage (Kristoffersen et al., 2021; Trevisan et al., 2022).

Therefore, the objective of this paper is to analyse solutions to CE adoption challenges in the textile and fashion industries, adopting a circular supply chain orchestration approach. This is important especially considering that textile and fashion supply chains are often long, fragmented and with an overwhelming presence of SMEs. According to the European Commission (2022), this sector in 2019 accounted for almost 160,000 companies in the European Union, and companies with less than 50 employees account for more than 90 % of the workforce. Thus, solutions for this kind of companies with limited financial and human resources should be sought. In this paper, we carry out a

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multiple case study methodology on a sample of five textile and fashion companies operating in the Prato (Italy) textile district, a historically circular manufacturing industry suffering from several of the challenges pointed out by CE literature. Orchestration responses to challenges observed empirically are then systematized and discussed in the light of the extant literature.

The paper is organized as follows. A literature review on the transition of the textile and fashion industries to the CE is provided in Section 2, which highlights the practices, the challenges faced and an overview of the potential responses. Section 2 also propose an integrative perspective on circular supply chain orchestration as the theoretical lens of our research. Then, Section 3 describes the research method adopted in this paper, including the research protocol followed for the multiple case study. The results of the research are then reported in Section 4, which illustrates the main findings from the five case studies in terms of challenges faced and responses activated by each case company. Section 5 discusses the results of the case studies in the light of the CE textile and fashion literature, highlighting the contributions and limitations of this study. Lastly, Section 6 reports the conclusions of the research, its managerial implications and some avenues for future research.

2. Literature Review

In this Section, we first discuss the environmental impact associated with the production and use of textile and apparel products, and the practices that allow the textile industry to move towards a CE (Section 2.1). Then, we illustrate the challenges faced by the textile and fashion industries moving towards CE, adopting a supply chain perspective (Section 2.2). In Section 2.3, we provide an overview of the solutions (practices and strategies) to these challenges. Lastly, in Section 2.4, we propose an integrative perspective on circular supply chain orchestration as the theoretical lens of our research.

2.1. The Textile and Fashion Industries Moving towards the Circular Economy

The production, use, and end-of-life of garments generate enormous levels of waste, carbon emissions, and water consumption (Wiedemann et al., 2020), due to factors related to the environmental impacts directly connected with textile production processes and bad usage habits such as 'fast fashion', which leads to a fast renewal of trendy and cheap clothes by consumers (Franco, 2017; Huang et al., 2021). Overall, only 20 % of all textiles are recycled worldwide (Koszewska, 2018; Sandvik and Stubbs, 2019). In addition, textile recycling often translates in downcycling activities such as the usage of post-consumer textile waste for making lower-value products such as cleaning towels or insulation, with very limited exploitation of the CE potential (Fischer and Pascucci, 2017). As a result, the textile industry is considered to be responsible for about 2 % of the world's greenhouse gas emissions, excluding the considerable impact of distribution and usage phase emissions that arise from clothes transportation and laundering (Sadowski et al., 2021; Virta and Räisänen, 2021).

It is therefore of utmost importance to favour a transition of the textile and fashion industries towards a CE. Literature has addressed the practices for the transition of textile supply chains towards CE (Köhler et al., 2021; Sandvik and Stubbs, 2019). These practices involve in particular a systemic modification in the design of textiles products, business models, consumption behaviours, and supply chain management (Bressanelli et al., 2021; Ellen MacArthur Foundation, 2017; Konietzko et al., 2020). First, the circular redesign of textile products allows extending the life of apparel and increasing their reuse and recycling potential. Durability, reparability and recyclability should be defined since the design phase, as these decisions will influence all the subsequent phases of the garment lifecycle (Rapsikevičienė et al., 2019). By conducting a stakeholder consultation of textile consumers, institutions and industrial players in four European regions, Boiten et al. (2017) highlighted the important role of principles such as zero-waste design for product-life extension and resource recovery in textiles. Pedersen et al. (2019) discussed the influence of organizational complexities in the design of CE solutions in the textile industry, highlighting the central role of designer for enabling multiple cycles in a CE. Second, service-based business models such as leasing and renting of clothing allows prolonging the lifecycle of garments through an increased reuse of clothes and recycling of textile fibres (Huynh, 2022). In addition, these business models focus on the user side, addressing green consumerism and changing consumption behaviours to challenge fast fashion (White et al., 2019). Sandvik and Stubbs (2019) carried out semi-structured interviews with stakeholders of the fashion industry and found that CE creates new business opportunities and can be seen as an active way to engage consumers. Todeschini et al. (2017) combined a systematic literature review with an empirical research with specialists in the textile industry, finding that an increased customer awareness about sustainability and green products is an important element of successful alternatives to fast fashion. Stål and Corvellec (2018) carried out a case study of several apparel companies located in Sweden, showing how consumers should be involved in circular business models especially in the collection of used clothes. Lastly, textile supply chain management should include reverse logistics to allow the effective collection, reuse and recycling of garments, reducing the need for virgin fibres and therefore the generation of textile waste (Stål and Corvellec, 2018). In this, regard, Kant Hvass and Pedersen (2019) investigated the role of take-back initiatives to enable reverse logistics through a case study of a global fashion brand. Fischer and Pascucci (2017) empirically analysed companies in the Dutch textile industry, finding that supply chain coordination, contracting and financial mechanisms are key elements for simulating new inter-firm collaboration for transitioning to CE.

Potentially, all these CE practices allows achieving environmental and economic benefits. Leal Filho et al. (2019) discussed textile recycling as a way to reduce the production of textiles from virgin fibres, hence reducing the consequent use of chemicals, water and energy. Dahlbo et al. (2017) showed that, through a Life Cycle assessment based on Finnish data, environmental benefits could be obtained by separating the collection of discarded textiles and through their reuse and recycling. Martin and Herlaar (2021) assessed several environmental and social benefits associated to the use of waste wool as a regenerated fibre under different supply chain configurations. Saha et al. (2021) surveyed more than 100 companies in the textile and clothing industry, and argued that, besides increased sustainability, companies can benefit from CE through both cost reduction and brand image. Desore and Narula (2018) found, through a literature review, that textile companies can gain competitive advantage from CE through both cost-saving strategies and strategies that are based on company's differentiation from competitors in the marketplace.

2.2. Obstacles and Challenges to Circular Economy Adoption in the Textile and Fashion Industries

Several challenges may prevent the establishment of circular supply chains in the textile and fashion industries. Barriers and obstacles to CE adoption focusing in particular on the supply chain level have been extensively investigated in the literature (see e.g., the literature reviews by Bressanelli et al. (2019) and Govindan and Hasanagic (2018)), and a number of studies have addressed specifically the textile industry (Abdelmeguid et al., 2022; Dulia et al., 2021; Franco, 2017; Hartley et al., 2022; Huang et al., 2021; Jia et al., 2020; Kazancoglu et al., 2020; Koszewska, 2018). Abdelmeguid et al. (2022) carried out a systematic literature review to investigate the challenges of CE implementation in the fashion industry. The authors found four 'hard' and two 'soft' aspects which could hinder the transition. Hard aspects include the difficulties in innovating business models towards CE, regulatory pressures, financial issues and stakeholder pressures. Soft aspects include organizational

and consumer related issues. Dulia et al. (2021) evaluated the risks associated with the adoption of circular supply chain practices in the textile industry through a survey on a sample of firms based in Bangladesh. Risks were aggregated in several categories: governmental, economic, technological, knowledge and skills, organizational, social and cultural, market, financial, and finally logistics risk. They found that, among others, the quality degradation of recycled products, the lack of a proper regulatory CE vision and the lack of consideration of the needs of the whole textile SC are the risks with the highest perceived priority. Franco (2017) explored the challenges that textile incumbent firms face when converting their products to adhere to CE principles, through a multiple case studies of European-based Cradle-to-Cradle certified companies in the textile and clothing industry. A set of critical factors that hinder companies in the textile industry to go fully circular was identified in the study, especially regarding the technological difficulties of recycling post-consumer textiles while maintaining the quality of the fibres, poor labour standards and conditions, and the lack of tools to assess and forecast the quantity, quality and timing of textile product returns. Hartley et al. (2022) identified the most pressing barriers to CE transition, based on data from 27 interviews with retailers and manufacturers in the Dutch textile industry. They found out barriers in the cultural, regulatory, market and technical domains. In particular, they found that the transition towards CE is hindered by the high costs of producing and marketing circular products, by a lack of awareness and interest by consumers, by a still predominant linear mindset of the companies operating in the value chain, and by obstructing regulations and laws. Huang et al. (2021) reviewed studies about CE barriers in the textile industry, and systematized twelve main risks, including low customer demand for recycled textile products, low collaborative innovation among supply chain partners, and financial issues exacerbated by the fact that the high initial costs are not compensated by economic benefits in short-term. Sirilertsuwan et al. (2019) explored barriers of reshoring and sustainable proximity manufacturing through a case study of 12 clothing companies. They found that both expensive labour production costs and a lack of textile industrial proximity network – able to deliver large production orders – prevent reshoring from Asia to European markets. Jia et al. (2020) reviewed 109 academic articles focusing on the implementation of CE in the textile and apparel industry, and drafted a conceptual framework in which ex-ante and ex-post barriers (such as the lack of financial support, the lack of information and technology systems, the lack of performance measurement systems, etc.) hinder the adoption of CE practices in the textile industry pertinent to the development and execution of a circular supply chain in the textile and apparel industry. Kazancoglu et al. (2020) sorted 25 barriers into nine categories, based on a review and a focus-group study of textile companies transitioning towards CE. The nine categories included management and decision-making processes, labour, design challenges, materials, rules and regulations, knowledge and awareness, integration and collaboration, cost issues and technical infrastructure. Lastly, Koszewska (2018) identified several barriers which hinder closing the loop in the textile and clothing industry, pertinent to consumer behaviour and education, wrong disposal practices and collection processes, lack of policy frameworks, a lack of commercially viable recycling technologies, and a general lack of traceability in the global waste chain.

The abovementioned literature findings about obstacles to CE adoption in the textile and fashion industry are systematized in Table 1 based on the categorization by Bressanelli et al. (2019). Their framework has been selected since it adopts a supply chain orientation similarly to this paper, and it has been used and referenced by several subsequent studies in the literature when referring to CE challenges. First, *economic and financial viability challenges* prevent the adoption of CE practices due to higher investments, costs, financial and operational risks. In the textile industry, the literature referred to higher risks related to venturing into unknown territories such as the circular redesign of clothes, leasing and renting fashion subscription models, reuse, and recycling of textiles (Hartley et al., 2022). These initiatives have higher costs and risks e.g. in research and development and in building the required supply chain infrastructure and logistics (Dulia et al., 2021; Sirilertsuwan et al., 2019). They thus could hamper competitiveness, especially in case virgin fibres have lower market prices (Kazancoglu et al., 2020). Second, *market and competition challenges* are related to market dynamics, as the risks of cannibalisation, to lose the know-how embedded in products and processes when discarded products are recovered by third parties, and to negatively impact the company brand image. In the textile industry, introducing new circular products can cannibalise *in space* (e.g. when recycled fibres offset virgin ones) and *in time* (when lower sales are entailed by a long use of clothes through leasing and design-to-last) the existing offering of clothes, and harm profitability in the long-term (Huang et al., 2021). Though they may be appealing for some customer segments, reused clothes and recycled fibres may also negatively affect the quality of products, and consequently harm the brand image of companies (Franco, 2017). Third *product characteristics challenges* relate to design issues: complex, designed-to-last products are unable to respond to fashion changes. In the textile industry, fast fashion, characterized by low prices and rapidly changing trends, leads to lower quality materials (Abdelmeguid et al., 2022). Fibres lifetime and quality before disposal is steadily declining, while the complexity of their composition is increasing (Jia et al., 2020). These are important barriers for textile recycling processes: composition of textile products makes them unsuitable for recycling, or make it difficult and costly to separate e.g. fibres, colours, plastic metal parts (zippers, buttons, etc.) and labels (Jia et al., 2020; Kazancoglu et al., 2020). Product complexity should be thus reduced at the design stage (Franco, 2017). Fourth, *standards and regulations challenges* relate to legislations, measures, and standards not aligned with CE. Despite the efforts that are currently made in some geographic areas such as the European Union through the CE Action Plan (European Commission, 2020), regulatory schemes still do not offer enough incentives for promoting textile waste prevention and circular clothes design (Dulia et al., 2021). The absence of an integrated policy framework to coordinate different stakeholders in the textile recycling SC negatively affects the industry. The same holds for standards and indicators: a common standard for textile recycling technologies is missing, while it is difficult to measure the tangible success of CE textiles initiatives (Jia et al., 2020). Fifth, *supply chain management challenges* are linked to supply chain configurations, actors, and relations. The textile literature recognizes the uncertainties regarding: the low and variable volume (in time and quality) of clothing waste; an increase in transportation in reverse logistics due to globally dispersed production and consumption networks; the difficulty in finding appropriate supply chain partners with aligned CE vision and the required skills, especially when the number of qualified workers is diminishing; the lack of effective communication, integration, and cooperation among the textile supply chain; the lack of traceability for textile products, where tracking and tagging technologies such as RFID and blockchain are expected to play in the future a strong role for textile recycling; and internal resistance to change due to cultural issues and unawareness of CE (Dulia et al., 2021; Huang et al., 2021; Jia et al., 2020; Kazancoglu et al., 2020). The key challenge is to connect the design phase with the supply chain processes, which are currently detached due to operational inefficiencies and the complexity of supply chains. Sixth, *technology challenges* refer especially to the inefficiencies of recovery processes. In the textile industry, the literature reports technological limitations for sorting textile waste and for the recycling of highly mixed-material compositions: leading to an unfavourable balance between collection, transport, and sorting costs and its sub-sequent value through recycling. Moreover, shredding affects quality badly, meaning that most fabrics are today downcycled into carpets or towels (Franco, 2017). Finally, *users' behaviour challenges* relate to users' perception and acceptance of circular products. In the textile industry, the challenge is to achieve consumer acceptance of second-hand or recycled clothing (Hartley et al., 2022), also given a perception of lower quality of 'green' products (Koszewska, 2018).

Table 1
– Systematization of challenges for circular textile supply chains, based on the framework by Bressanelli et al. (2019).

Category	ID	Challenge	Definition	Contextualization in the textile industry	Studies in the textile industry (references)
Economic and financial viability	1	Higher investments	Providers of CE solutions may incur in longer payback time, due to higher investments and the decoupling between costs and revenues (e.g., in case of servitisation). This leads to a postponement of the economic break-even point	Higher risks (especially for fashion brands) related to venturing into unknown territories as circular redesign of clothes, renting and leasing fashion models, reuse and recycling of textiles: these initiatives have higher costs (e.g., in research and development and in building the required infrastructure and logistics) and could hinder competitiveness.	(Dulia et al., 2021; Hartley et al., 2022; Huang et al., 2021; Jia et al., 2020; Kazancoglu et al., 2020; Sirilertsuwan et al., 2019)
	2	Financial risks	Providers of CE solutions may incur in financial risks (e.g., due to servitisation)		
	3	Operational risks	Providers of CE solutions may incur in operational risks (i.e., costs of product damages, maintenance, repair, etc.)		
Market and competition	4	Cannibalization	Circular products (e.g., recycled or designed to last longer) can cannibalise the existing ones, affecting company revenues and sales	Introducing new circular textile products can cannibalise *in space* (e.g., recycled fibres off-set virgin ones) and *in time* (long use of clothes means reduced sales) the existing offering of clothes, especially for fashion brands. Reused clothes and recycled fibres may affect quality and consequently reduce the brand image of companies.	(Franco, 2017; Huang et al., 2021)
	5	Know-how access	CE activities accomplished by a third party (e.g., remanufacturing) may lead to a loss of control by the manufacturer of the know-how embedded in the products		
	6	Lower Brand Image	CE activities accomplished by a third-party (e.g., remanufacturing) may have a negative impact on the OEM brand image if not performed properly		
Product characteristics	7	Fashion change	Fashion change quickly, and products designed-to-last are unable to respond to such changes	Fast fashion, characterized by low prices and rapidly changing trends, leads to lower quality materials. Composition of textile products makes them unsuitable for recycling, as in case of colour separation or the presence of plastics and metals. Product complexity should be reduced at the design stage.	(Abdelmeguid et al., 2022; Franco, 2017; Jia et al., 2020; Kazancoglu et al., 2020)
	8	Product complexity	Product complexity by design (e.g., presence of toxic materials, non-modular design) increase the difficulties in managing recovery processes		
	9	Mass customisation	Mass customisation pushes towards personalised products, which leads to a higher complexity for recovery processes		
Standards and regulation	10	Taxation and incentives unaligned	Current taxation systems, policies and financial incentives are not aligned with CE	Current regulatory schemes do not offer enough incentives for textile waste prevention and circular clothes design. The absence of an integrated policy framework to coordinate different stakeholders in the textile recycling negatively affects the industry. The same holds for standards and indicators.	(Abdelmeguid et al., 2022; Dulia et al., 2021; Hartley et al., 2022; Huang et al., 2021; Jia et al., 2020; Kazancoglu et al., 2020; Koszewska, 2018)
	11	Measures, metrics, indicators unaligned	Current indicators, measures and metrics are not aligned with CE		
	12	Lack of standards	Current standards (processes, activities, materials) are not aligned with CE		
Supply chain management	13	Return flows uncertainty	Uncertainty about quantity, mix, quality, time and place of returns of end-of-use products	Low and variable (in time and quality) volumes of clothing waste; increase in transportation due to globally dispersed production and consumption networks, difficulties in finding partners with similar future vision and the required skills; lack of effective communication, integration, and cooperation among supply chain members; lack of traceability of textile products; internal resistance to change.	(Dulia et al., 2021; Franco, 2017; Huang et al., 2021; Kazancoglu et al., 2020)
	14	Increase in transportation	CE may increase transportation if all products are sent back to producers, especially in case of geographical dispersion		
	15	Availability of suitable skills and supply chain partners	Difficulty in finding appropriate supply chain partners, with aligned CE goals and appropriate skills		
	16	Lack of coordination and information sharing	Lack of a close collaboration and information exchange among the supply chain, especially within global configurations (due to competition among supply chain tiers, information sensitivity, IT system integration, poor planning of activities, etc.)		
	17	Lack of traceability	Lack of product traceability, which otherwise would improve collection and recovery processes		
	18	Cultural issues	Internal resistance to change ('linear lock-in'), limited awareness and commitment		
Technology	19	Eco-inefficiency of processes	Recovery processes (e.g., recycling) may be inefficient from a technological perspective and expensive	Lack of technology for sorting textile waste and for the recycling of highly mixed material compositions. Advanced recycling technology is required to complement the inefficient mechanical recycling: shredding affects quality badly, meaning that - in reality - most fabrics are not recycled but downcycled into carpets or towels.	(Abdelmeguid et al., 2022; Dulia et al., 2021; Franco, 2017; Hartley et al., 2022; Huang et al., 2021; Kazancoglu et al., 2020; Koszewska, 2018)
	20	Technology improvements	Fashion change quickly, and products designed-to-last are unable to participate in such continuous technology improvement		
	21	Data privacy and security	Collection of intelligent products at the end-of-use may be hampered by concerns about privacy and data security		
Users' behaviour	22	Loss of ownership value	Some CE offerings may lead to a loss in ownership value, especially in the case of servitisation	The challenge is to achieve consumers' acceptance of circular offerings, such as second-hand or recycled clothing, also given the common belief that green products are	(Abdelmeguid et al., 2022; Dulia et al., 2021; Hartley et al., 2022; Huang et al., 2021; Kazancoglu et al., 2020; Koszewska, 2018)
	23	Careless	Users' who do not own products has no		

Table 1 (*continued*)

Category	ID	Challenge	Definition	Contextualization in the textile industry	Studies in the textile industry (references)
		behaviour	liability on them, so a careless behaviour in product use and conservation may occur	more costly than alternatives, and the perception of their lower quality.	
	24	Willingness to pay	Price of circular products may be higher compared to the price of ordinary ones. Users may have a different willingness to pay for circular products, not perceiving their value		

2.3. Overcoming the Challenges to Circular Economy Adoption in the Textile Supply Chain

A few studies in the literature point out practices and strategies to overcome the CE adoption challenges in the textile and fashion industries, (also) at the supply chain level. Diabat et al. (2014) analysed the enablers for implementing sustainable supply chain management in Indian textile industries and pointed out five main practices: adoption of safety standards, adoption of green practices, community economic welfare, addressing health and safety issues, and employment stability. Huang et al. (2021) suggested two main strategies to support the Taiwanese textile industry overcome the barriers to CE, namely an infrastructural strategy and a platform strategy. Concerning the demand side, they suggest that supporting novel business models could bring greater benefit than implementing consumer education programs. On the supply side, they suggest that Taiwanese companies invest in circular textile design and manufacturing technologies, supported by networking and horizontal and vertical partnerships in the supply chain. Moreover, they suggest the development of an information exchange platform to help the textile supply chain networking, collect data on recycled materials flows and share knowledge about circular textile innovation. Jia et al. (2020) identified as key aspects for building a circular supply chain in the textile industry the product stewardship (e.g., product design or re-design for the environment), and building collaborative relationships. Majumdar et al. (2021) through a literature review and experts' opinion identified twelve risks and thirteen mitigation strategies for sustainable clothing supply chains. Among them, developing agility in supply chains; multiple green sourcing and flexible capacity; adoption of green practices; trust, coordination and collaboration; and alignment of economic incentives and revenue sharing are the top five strategies pointed out for risk mitigation in environmentally sustainable clothing supply chain. Supply chain partners should develop a symbiotic resource dependence by building good reputation, co-optation, long-term contracts, minority ownership (trust, coordination and collaboration). Relationships should be strengthened by aligning economic incentives and sharing revenues. Multiple green sourcing and flexible capacity allow avoiding the risk of opportunistic behaviour at the demand or supply side. According to Saha et al. (2021), who carried out a survey within 114 textile and clothing companies in Bangladesh, Vietnam and India, a holistic approach is needed to overcome the challenges to CE implementation, that involves the collective effort from the industry, host government's incentives, their buyers and above all the conscience of the end-users. Franco (2017) pointed out that a key to be successful in textile product redesign is a strong buyer-supplier cooperation, especially through the competence of second and third-tier supplier of clothing companies to develop innovations for circular products. Driving (or hindering) factors stand in: the partner's position in the value chain; the relative customer-supplier power balance; the level of common vision and trust. Also, Franco (2017) noted that the idea of a disruptive evolution towards CE may be misleading: activating product innovation, consumer demand, manufacturing, business model changes and take-back systems altogether requires time, and '*will be the result of well-coordinated actions initiated at different parts of the system*' (ibid., p. 842). Finally, Cai and Choi (2020) highlighted that Corporate Social Responsibility is often a driver for sustainable SC in the textile and fashion industry and, based on a literature review, identified several supply chain management practices for sustainability. Sustainable textile supply chain management is facilitated by tight international collaborations of supply networks, adoption of 'design for circularity' practices, adoption of sustainable dyeing processes, the selection and evaluation of suppliers based on social and environmental criteria (besides cost ones) and adopting clean production approaches.

2.4. An Integrative Perspective on Circular Supply Chain Orchestration

Although solutions to overcome the CE challenges in the textile and fashion industries have been investigated (Section 2.3), the proposed practices and strategies are still largely fragmented and analysed in isolation, without the help of an overarching theory to understand how circular supply chains should be managed and coordinated. To this regard, the resource orchestration view has emerged recently as a promising research stream to understand how firms should best manage their resources for increased competitive performance (Kristoffersen et al., 2021). The resource orchestration view extends the resource-based view by drawing upon the resource management framework and the asset orchestration framework, by explicitly addressing the actions to effectively structure, bundle, and leverage firm resources (Sirmon et al., 2011). While the resource-based view suggests that a firm can achieve competitive advantage by creating specialized, difficult-to-replicate resources and capabilities, the resource orchestration view extends this concept to address an efficient and effectively orchestration of resources and capabilities (Asante et al., 2022).

However, no single company can achieve CE in isolation (Bressanelli et al., 2019; Calzolari et al., 2021; Fontell and Heikkilä, 2017), since in modern production and consumption systems a single firm controls only a limited part of the process and of the systemic set of actions that should be put into place, as exemplified in Section 2.1 for the textile industry. Therefore, resource orchestration should be carried out across the supply chain – including suppliers, customers, and other stakeholders – to achieve CE (Asante et al., 2022; Sudusinghe and Seuring, 2022; Wong et al., 2015). Research adopting this approach is still at a nascent stage, and literature applied the resource orchestration view to supply chains in a scattered way. Through a literature review, Wong et al. (2015) proposed resource orchestration as a theory to explain 'green' supply chain integration practices, and suggest that future research should further detail the practices for acquiring, bundling, and leveraging resources. Zaoual and Lecocq (2018) investigated the activities of network orchestrators in three eco-industrial parks for facilitating new forms of interorganizational cooperation within industrial ecosystems. The four identified activities are the identification of value, the generation of trust among the ecosystem actors, the activation of industrial ecology innovations, and the institutionalization of industrial ecology mechanisms. Hansen and Schmitt (2021) carried out a longitudinal case study of a large chemical company that implemented cradle-to-cradle innovations across its value chain. They found that innovation processes should be actively supported by orchestrators, who may either push innovation through hierarchical power, promote innovation through expert knowledge, translate the different languages spoken in the firm, and build relationships inside

and outside the company. Palmié et al. (2021) carried out a multiple case study to gain insights on the configuration of circular business models of firms that orchestrate resource-sharing solutions. They identified four transition pathways, according to the resources involved and on the interactions among actors: the lean orchestration strategy requires little resource modification and low actor interaction; the resource-driven orchestration strategy needs substantial resource modification; the actor-driven strategy requires a high actor interaction; and the dual orchestration strategy requires both substantial resource modification and high actor interaction. Asante et al. (2022) developed a framework to describe how construction and demolition companies can orchestrate resources for implementing CE, showing that orchestration can be integrated both horizontally (across the scope of the firm) and vertically (across the managerial levels), as well as across the various stages of firms' evolution from growth to maturity and decline. Trevisan et al. (2022) carried out a systematic literature review to investigate how circular ecosystems are structured, finding that orchestration is key for network coordination and for ensuring that circular principles are implemented, following a non-hierarchical and collaborative governance mechanism. Huynh (2022) carried out a multiple case study to investigate fashion firms' orchestration mechanisms towards CE. They found three circular business models archetypes for the fashion industry: (i.) the blockchain-based supply chain model, focused on the track-and-tracing of materials and products in the supply chain; (ii.) the service-based model, focused on leasing, renting and subscriptions of clothing; (iii.) the pull demand-driven model, focused on contrasting fast fashion by switching supply chain forecasting and planning process from push to demand-pull mechanisms. Lastly, Parida et al. (2019) developed a model to support the orchestration of industrial ecosystems by large manufacturing companies in their journey towards CE. Accordingly, ecosystem transformation should be put in place, by the means of (i.) *standardization*, through lobbying for setting formal industry standards and through informal standardization to pursue technological standard co-development; (ii.) *nurturing*, from bearing early investment costs to supporting the development of routines, processes, competences as well as the sharing of knowledge; (iii.) *negotiation* mechanisms, to reduce conflicts, control the inclusion of new partners, and safeguard interests of partners by setting rules of the game based on give-and-take relationships.

Based on the abovementioned literature, we propose to follow an integrative perspective on the (i.) resource orchestration view, (ii.) supply chain orchestration, and (iii.) CE, and adopt a circular supply chain orchestration approach as the theoretical lens to frame our research. Based on the previous literature, we define circular supply chain orchestration as '*a set of purposeful actions by a focal firm that coordinates and manages diverse interests, ensures alignment among circular supply chain members, and structures, bundles and leverages resources to create circular value*' (Asante et al., 2022; Dhanaraj and Parkhe, 2006; Parida et al., 2019; Trevisan et al., 2022; Wong et al., 2015). Such integrative approach would help in structuring potential solutions (strategies and practices) to CE challenges. We posit that adopting this approach could contribute to knowledge development on both the CE and supply chain management research domains, both at a general level and in particular for the textile and fashion industries.

3. Methods

The objective of this paper is to analyse solutions to circular supply challenges in the textile and fashion industries, according to a circular supply chain orchestration approach. To do so, a multiple case study methodology is applied to a sample of five companies operating in the Prato (Italy) textile district. Prato is one of the most important textile districts in Europe, and CE has been practiced in the district for more than a century. Its most distinctive products, in fact, have always been yarns and fabrics made of recycled wool, produced locally, starting from rags and textile processing scraps. The district is made of SMEs, each specialized in one or more stages of the production process: according to the local Chamber of Commerce, all the companies in the Prato district have less than 250 employees and only very few have a turnover greater than 50 M€. As shown in Fig. 1, the recycling process

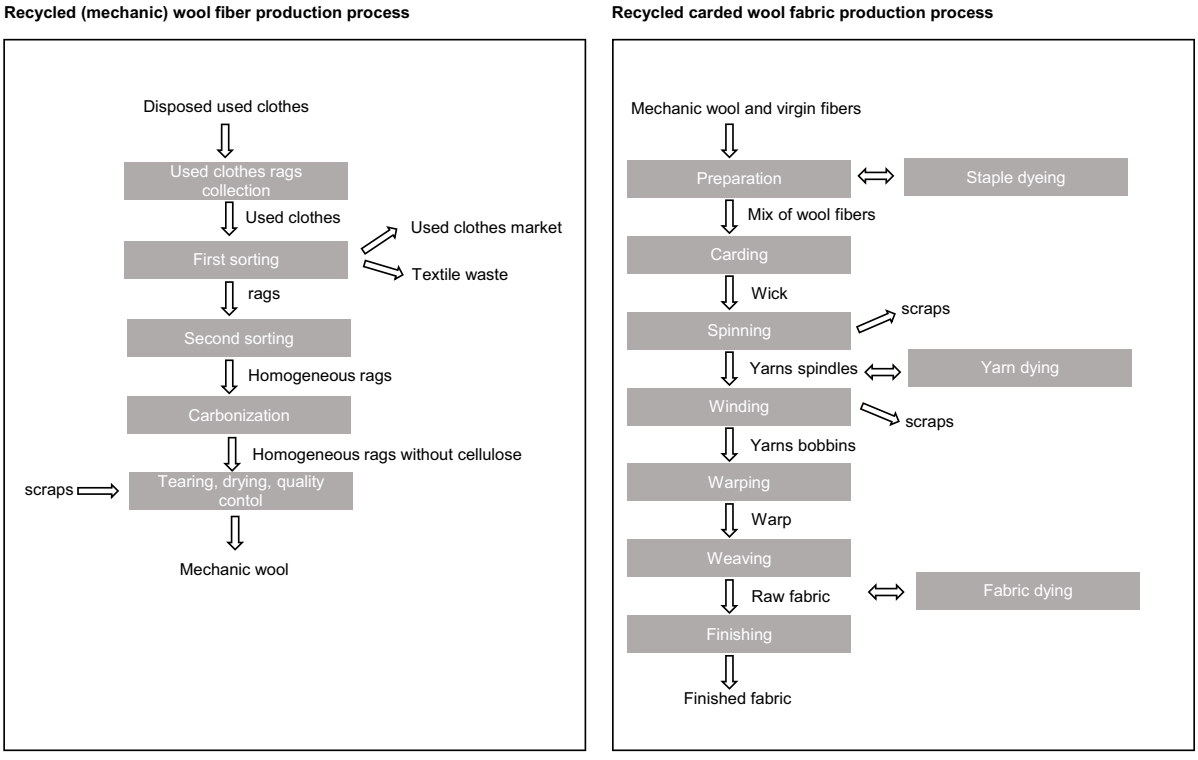

Fig. 1. – Recycled (mechanic) wool fibre production process (left-hand side), recycled carded wool fabric production process (right-hand side).

(left side of Fig. 1) starts from post-consumer and pre-consumer material and returns them to the fibre state. Post-consumer materials are used clothes and rags, while the pre-consumer ones are by-products and textile scraps from the wool production process (e.g., spinning and winding scraps). The recycling process consists of 4 phases. With the first sorting, a decision is made whether to send the garment to the second-hand market, send it to the recycling process, or dispose of it as waste. With the second sorting, the material is classified according to colour, composition, and quality: accessories such as zippers, buttons, labels, and linings are cut, and the material is either immediately cut into pieces (rags) or stored for later processing. This (second) sorting activity requires to quickly recognize the composition of rags by touch, and it is carried out manually by highly skilled personnel, the so-called '*cenciaioli*'. The carbonization phase consists of removing cellulosic impurities (mainly cotton and viscose) from rags using hydrochloric acid sprayed as vapor in solution. This step is carried out so to not affect the composition and colour of the materials. Finally, in the tearing phase, rags are frayed and washed. The output of the recycling process is called 'mechanic wool' which is a raw material used in the fabric production process. The fabric production process (right side of Fig. 1), then, consists of (at least) seven phases. In the preparation phase, recycled and blended fibres are mixed, following precise recipes, to obtain a yarn of the desired composition and colour. These recipes are developed in a laboratory by specialized technicians called '*feltrinisti*'. In case it is not possible to obtain the desired colour just by mixing undyed fibres, a staple-dying process is required. Through the carding phase, blended fibres are transformed into a carded web and subsequently into a thin band of slightly twisted textile fibre with a cylindrical cross-section named *wink*. With the spinning phase, the wink is transformed into a *spindle-wound yarn* thanks to the coordinated actions of twisting and stretching. Spindles are then converted in *bobbins* in the winding phase. This phase is required both to package the yarn in a format more suitable for subsequent processing, in addition in this phase the quality of the yarn is improved as any defects in the yarn are checked and eliminated. In the warping phase, bobbins are converted to *warps* that are subsequently used in the weaving phase where warp and weft are interlaced to form a raw fabric. Finally, in the finishing phase, raw fabrics are transformed through a series of processes into finished fabrics with special aesthetic or mechanical characteristics.

To perform this production process, the Prato district has organized itself as around open, multi-tier supply chains characterized by a high degree of deverticalization and specialization (Bressanelli et al., 2022). Main actors of this supply chain are phase suppliers and first-tier suppliers. Phase suppliers are specialized in one or more of the phases in Fig. 1. Their size can vary considerably, their production facilities range from small artisan workshops to larger industrial establishments (especially in the finishing phase). First-tier suppliers, instead, are yarn or fabric suppliers for the fashion market. They design and engineer yarns or fabrics, procure raw materials (fibres, yarns, or raw fabric), and feed them into a production process that rarely takes place in-house but, instead, involves numerous phase suppliers. First-tier suppliers are usually highly deverticalized firms whose manufacturing capability depends on their phase suppliers. First-tier suppliers interact with apparel and fashion brands, representing the 'window to the market' for the whole district.

The Prato textile district, thus, is particularly well-suited for this study as it allows investigating how supply chains deal with the challenges characterizing the circular transition of the textile industry. The first phase of the empirical analysis was aimed at acquiring information regarding the challenges faced to preserve, after years of crisis, the companies' valuable historical know-how related to wool regeneration processes and to satisfy a fashion market increasingly interested in circular and environmentally sustainable products. To do this, we participated in a meeting with more than 50 textile entrepreneurs in which we discussed how the district was evolving and the orchestration mechanisms employed to lead the change and thrive. Following the meeting, five case companies, which were clearly either proactively implementing or undergoing some sort of orchestration mechanisms, were selected. The case selection was thus purposeful. The selected case companies (Table 2), in fact, cover one or more phases of the production process, have different roles in the supply chain (phase suppliers, first-tier suppliers, fashion brands), and are characterized by different levels of orchestration. Specifically, we selected two phase suppliers (PH1, PH2), two first-tier suppliers (FT1, FT2), and one local fashion brand (FASH) selling garments made of recycled textiles. All of the case companies – except FASH – are active since several decades, have always been involved in the production of recycled textiles and have a good reputation in the district.

Data were collected following the interview guide included in the Supporting Materials. First, we collected and analysed data from secondary sources (social media, website, and annual/sustainability reports) to understand what products/services each company offered, what certifications they had, and what circular initiatives were in place. Secondly, we interviewed the CEO/owners of each company. The interviews were aimed at investigating the orchestration mechanisms companies were implementing or undergoing, and their rationale. The interviews lasted about 2 h each, were held in the company's headquarters and were followed by a visit to the company production plant. During the visit, the authors' interacted with production managers and workers: these interactions were aimed to discuss with front-line employees the problems related to the practical implementation of the above-mentioned orchestration mechanisms. The interviews as well as all the formal interactions with companies' employees were accurately transcribed and coded. Data were subsequently

Table 2
– Case studies.

Company	Main role in the supply chain	Main activities	Employee	Turnover	Year of foundation
PH1	Phase supplier	Spinning	8 (2021)	0.8 M€ (2021)	1973
PH2	Phase supplier	Weaving	28 (2020)	1.9 M€ (2020)	1980
FT1	First tier supplier	Design Supply chain coordination Marketing & sales Sourcing of raw materials Preparation	44 (2020)	70.2 M€ (2020)	1943
FT2	First tier supplier	Design Supply chain coordination Marketing & sales Sourcing of raw materials Carbonization Preparation	42 (2020)	7.6 M€ (2020)	1951
FASH	Fashion brand	Design Supply chain coordination Marketing & sales	11 (2021)	1.8 M€ (2021)	2017

analysed to identify for each case the most significant orchestration mechanisms employed, their rationale, and to unveil implementation details.

4. Results

This section illustrates the main findings from the five case studies, in terms of challenges faced, and responses activated by each case company.

4.1. Phase Supplier 1

PH1 is a small spinning mill founded in the 1970s, specialized in the production of recycled carded wool. Like most the carded spinning mills operating in Prato recycled wool supply chains, PH1 suffers structural weaknesses. The price first-tier suppliers are willing to pay for the spinning process of recycled wool is limited due to the small margins that, on average, they have in selling carded wool yarns and fabric to fashion brands. Therefore, spinning mills are now the weakest link in the carded wool supply chain, while most of them struggle to survive. While in the 80s PH1 had almost 600 competitors within the district, today the number of spinning mills operating in Prato is around 70. PH1 and phase suppliers in general are thus not profitable enough to upgrade and digitize their production equipment. The equipment used to produce carded wool yarns is big, not flexible (they can cover only a limited count range) and devised for high-volume, 24/7 production. However, the overall demand for carded recycled wool is way smaller than it used to be when those plants were set up. In addition, the demand for this type of yarn is highly seasonal and the variability (in time and mix) in volumes of pre- and post-consumer waste for the sorting process challenges production capacity saturation and cost efficiency of phase suppliers.

PH1's orchestration response to these challenges is articulated in several ways. First, PH1 is participated by a first-tier supplier that, if needed, produces yarns to stock to ensure PH1's stable cash flow in low volume periods. Second, being aware that the overall spinning mills capacity in the district is limited and progressively diminishing, PH1 reserves capacity in peak months (February to June) only to those customers who placed orders in September to December. De facto, PH1 forces its customers to produce to stock to ensure an adequate level of service at peak times. According to the PH1's CEO, best-in-class first-tier suppliers should buy shares of the spinning mills they work with if they want to guarantee themselves a production capacity and preserve skills that otherwise would be lost forever. He wishes for larger participation of first-tier suppliers in its company capital as well. While insourcing the spinning process is undoubtedly a costly operation, in the long-term this is a strategic weapon from a supply chain point of view, leading to several strategic advantages: securing capacity in peak periods, obtaining greater collaboration and involvement in the design and engineering of new collections, better production planning and control with greater efficiency during peak periods, and an overall better customer service.

4.2. Phase Supplier 2

PH2 is a phase supplier specialized in the weaving process of recycled wool. PH2 stressed how many first-tier suppliers producing carded fabric, due to their extreme deverticalization and the increasingly small size, have now limited know-how in terms of the manufacturing process and production planning and control. The production of small batches leads to significant set-up costs of phase suppliers as PH2 that, coupled with low prices of recycled wool, compromise the overall suppliers' marginality. The fragmentation of the textile production processes due to the great deverticalization of the supply chain drastically reduced supplier involvement in the design of (recycled wool) collections. On the other hand, first-tier suppliers often fail in orchestrating the production process and no longer offer the technical support they used to provide in the past.

PH2 responded to such a situation in two ways. First, increasing the share of capacity allocated to customers ordering larger lots (often located outside the district, and producing high-end combed wool fabric for men). Second, saturating their capacity through the make-to-stock production of raw fabrics. PH2 sells raw fabrics through a controlled company purposely created. In so doing, PH2 saturates its production capacity in periods when it would have been unused. The marginal cost of producing these row fabrics is low and consequently, this complementary business is rather profitable.

4.3. First-Tier Supplier 1

FT1 is a first-tier supplier, designing and selling jerseys and fabrics. Although its product range is wide and not limited to woollen fabrics, recycled wool has always been the company's core business. Regarding suppliers, FT1 created an internal process to collect and reuse as raw materials the leftovers and scraps created during the spinning process. Regarding its customers, FT1 launched a pilot project aimed at recycling offcuts and scraps produced during the garment making process based on the establishment of a circular supply chain in collaboration with selected garment makers. However, also FT1 recognizes several circular supply chain challenges, such as demand seasonality, the variability (in mix and time) of post-consumer textiles, the lack of effective communication and cooperation among the different supply chain members, or the lack of skilled labour force that are needed to carry out some critical activities (e.g., sorting) that are mostly manual and require long-time experience. In fact, the distinctive skills related to the regeneration of wool are held by people close to retirement and are now at risk, since years of crisis have greatly reduced the appeal of the textile industry for the younger generations, thus preventing a proper generational turnover.

FT1 successfully responds to these obstacles by developing a superior capability as supply chain orchestrator. In fact, FT1 is a highly deverticalized company with a relatively small number of employees. It directly designs and sells textile fabrics, while entirely outsourcing production to suppliers. FT1 successfully manages its local supply chain, composed of 50 phase suppliers (9 raw materials suppliers, 10 spinning mills, 1 coning mill, 6 warping mills, 19 weaving mills, 11 finishing mills), entirely located in Prato, of which it has succeeded in exploiting and enhancing the enormous expertise in wool textile processes. Contrary to what happens for most of the first-tier suppliers, the relationship is not informal and based and spot transactions, instead, it is based on long-term agreements bringing several benefits, ranging from capacity saturation of phase suppliers to financial support in the upgrade of production equipment required to comply with FT1 needs. To facilitate suppliers' coordination and supply chain visibility to final customers, FT1 has created an Information Technology platform allowing the exchange of information inside the network, related to production, sustainability and accounting data. Leveraging its superior circular supply chain orchestrator capability, FT1 was able to implement an effective sustainability-focused business model and marketing strategy, that has led to creating a brand image for the company in the fashion industry and to selling recycled fabrics as medium-to-high-end products while at the same time producing a massive amount of fabric. Lastly, FT1 has created an Academy, i.e., an innovative cultural hub where stakeholders such as students or professionals can learn the art of textile design and production, to increase the appeal of the textile industry for youngsters, thus creating ‘designers for sustainability’ able to conceive garments from recycled fabric and recyclable garments.

4.4. First-Tier Supplier 2

FT2 is a first-tier supplier of fabrics and carded yarns, producing also recycled wool, founded in 1951. FT2 internally designs its yarns, while

outsourcing the core production processes (including carding, spinning and weaving) to phase suppliers. As in the other cases, FT2 recognizes several obstacles hindering the prospering of the recycled wool supply chain. Regarding standards and regulation, the transposition of the End-of-Waste and REACH regulation into the Italian law, classifies both pre- and post- consumer textiles as 'special waste', instead of by-products or secondary raw materials. Therefore, the reuse of production scraps generates additional costs to obtain the certifications to treat such 'special waste' and the need for managing all the documentation required to handle these materials. These legal-administrative constraints represent a threat to the survival of the very small companies upstream of the carded wool supply chain, especially those involved in the sorting process. Moreover, and since the phase supplier's base is shared among several first-tier suppliers, it is very difficult to protect know-how and innovations.

To respond to these challenges, FT2 adopted several orchestration mechanisms. To preserve the know-how and support the fragile ecosystem of SMEs involved in the circular supply chain of recycled wool fibres, FT2 has a very active role inside the national Recycled Textile Association. Such an association today has approximately 170 members and is hosted in FT2's headquarters. FT2 is also part of the working group by the national Ministry of Environment, for the transposition of the End-of-Waste and REACH regulations into Italian law. In addition, FT2, together with the Italian Recycled Textile Association, is now promoting the birth of a consortium specialized in the sorting process of textile waste. Second, FT2 is vertically integrated since it owns complete carbonization and water-shredding plants, through which it carries out the whole recycling cycle (i.e., carbonization, tearing, fraying, hydro extraction, and drying) from rags to regenerated wool fibre. Every year, FT2 transforms about 5000 tons of textile waste, and showing an effort to integrate vertically at upper stages of the wool recycling process. Third, FT2 has recently implemented a label that states the composition and allows traceability of its textile products, in collaboration with a Dutch company providing a certified and independent assessment of the environmental impact of products and producing labels that made this information accessible through a QR Code. Lastly, to raise awareness of CE, FT2 has also started the production of garments made in collaboration with Art and Design Institutes. These garments are designed for repair and regeneration, with all seams made from natural fabrics without using thermos-adhesives or synthetic materials, which compromise the possibilities of recycling.

4.5. Fashion Brand FASH

FASH is a start-up apparel and fashion brand company selling fully recycled garments (such as sweaters in regenerated wool), founded in 2017. FASH garments are almost entirely made in Prato using raw materials such as recycled yarns (sourced from first-tier suppliers located in Prato), old cashmere sweaters, old cotton jeans, and cotton recycled from industrial waste. FASH converts these raw materials into cashmere sweaters, cotton sweaters and denim fabrics, t-shirts and polo shirts, beach towels, and shawls. These garments are made of 92 % recycled fibre bringing back to life 3.738 tons of recycled textile material. The whole production process is carried out by a dozen of phase-suppliers located in the Prato district (spinning, weaving, packaging, labelling), and does not include the dyeing phase to reduce the use of energy, water and chemicals. Several challenges prevent the scale up of wool circular supply chains. Fast fashion industry promotes the use of synthetic fibres (against recycled wool), which are lighter and cheaper. This led to reduction of the carded wool market share in the past. On the other hand, low quality materials and processes often used to reduce costs harm their durability. In addition, garments not designed with regeneration as an objective may not overcome the sorting and selection process (e.g., wool garments with gaskets in polyester). Composition of textile products makes them unsuitable for recycling, as in case of colour separation or the presence of plastics and metals. Lastly, end users may have a different willingness to pay for circular products, not perceiving their value.

FASH responds to these challenges through its orchestration ability to exploit the market interest for circular textiles, to bring, with its own brand and without intermediaries, Prato's textile art and tradition to the end customer. Despite being recycled products, FASH garments are not low-cost merchandise, but items full of extra-economic meanings that lead final customers and make them willing to pay a premium price. By doing so customers feel to contribute to the well-being of the environment, the FASH suppliers base, and of the local community as well, since for every purchase made in the online shop, FASH will make a donation to support a local social project. To avoid overproduction, reduce inventory and facilitate suppliers' capacity planning, FASH adopts a no-discount policy and, when FASH launches new products, it puts them on pre-sale to facilitate scheduling. FASH has also recently launched 'collaborative' CE initiatives, characterized by the involvement of end customers in its circular business model, ranging from garment collection services (that allows customers to return via ship or pickup service old woollen or cashmere sweaters and receive a discount voucher in exchange), to garment co-design that, coupled with the aforementioned pre-sale policy is aimed at further reducing inventory and waste and at strengthening the bond between customers and their clothes, which is the first step towards a more sustainable consumption of fashion products.

5. Discussion

This section discusses the results of the case studies in the light of the CE textile and fashion literature. Section 5.1 systematizes the actions found in the cases according to the circular supply chain orchestration perspective, and classify them according to the framework by Parida et al. (2019), to discuss how they contribute to the standardization, nurturing and negotiation mechanisms of supply chain orchestration. We also match these actions with the CE challenges and responses found in the literature about the textile industry that were illustrated in Section 2. In Section 5.2, instead, we discuss the main contributions of this study, as well as its limitations.

5.1. Circular Supply Chain Orchestration: Mechanisms and Responses to Challenges in the Textile and Fashion Industries

The case studies described in Section 4 concerns SMEs belonging to the Prato regenerated wool supply chain. The cases emphasize the relationships between first- and second- tier (phase) suppliers, often overlooked in the literature, as well as the role of start-up companies downstream in the supply chain. As quite common in the textile industry, the cases confirm that the supply chain is fragmented, with several small or micro companies, seasonal demand, uncertainty about the continuity in orders due to little coordination, and a tendency towards opportunistic behaviour by supply chain members – especially first-tier suppliers.

Through the case studies we found several of the challenges mentioned in the literature, as well as several responses actions. More specifically, 10 circular supply chain orchestration responses emerged from the cases, namely: (i.) institutional actions; (ii.) financing the renovation of production equipment; (iii.) greater information exchange; (iv.) vertical integration; (v.) traceability through digital technologies; (vi.) initiatives to increase attractiveness to younger generations to prevent the loss of skills; (vii.) customer engagement and brand positioning; (viii.) co-design out waste; (ix.) strengthening of legal bonds; (x.) market alternatives for capacity saturation. These 10 circular supply chain orchestration responses have been compared with previous literature in the textile industry in Table 3, and classified according to the orchestration framework by Parida et al. (2019), which considers the three orchestration mechanisms of standardization, nurturing and negotiation. This framework was chosen because of its systemic

Table 3
– Circular supply chain orchestration mechanisms.

Orchestration mechanism (adapted from Parida et al., 2019)	Operationalization of circular supply chain orchestration mechanisms in the textile industry (reference to case in the empirical study)	Studies in the textile industry (References from Section 2.3)
Standardization - Actions such as lobbying and other schemes to formulate and establish formal and informal standards	1. Institutional Actions (FT2): lobbying at an institutional level to change regulations and remove bureaucracy constraints	(Diabat et al., 2014; Saha et al., 2021)
Nurturing - Drive the growth of circular supply chain partners by bearing investments costs, developing routines, processes and competences, facilitating the sharing of knowledge	2. Financing the renovation of production equipment (FT1): financing the renovation and the digitization of production equipment of the phase suppliers to have up-to-date technologies and reduce production costs	
	3. Greater information exchange (FT1): greater information exchange among circular supply chain partners supports long-term agreements and an enhanced integration at an operational level	(Cai and Choi, 2020; Franco, 2017; Huang et al., 2021; Jia et al., 2020; Majumdar et al., 2021)
	4. Vertical integration (FT2): integrate vertically phase suppliers to improve planning, control and capacity saturation of previously outsourced activities	(Cai and Choi, 2020; Franco, 2017; Huang et al., 2021; Jia et al., 2020; Majumdar et al., 2021)
	5. Traceability through digital technologies (FT1, FT2): track and trace of material composition and processes to improve operations monitoring and back claims of a circular and sustainable supply chain	(Franco, 2017; Huynh, 2022)
	6. Initiatives to increase attractiveness to younger generations to prevent the loss of skills (FT1): increase attractiveness of the jobs and favours generational turnover e.g., by setting up Academy and by involving students in design contexts and company visits	
	7. Customer engagement and brand positioning (FASH): promoting sustainable and local production as valuable aspects and involving end customers as active parts in the take-back process	(Huang et al., 2021; Saha et al., 2021)
	8. Co-design out waste (FASH): co-designing clothes with suppliers to improve the sorting and regeneration processes	(Cai and Choi, 2020; Franco, 2017; Huang et al., 2021; Jia et al., 2020)
Negotiation - Set the rules of game based on give-and-take relationships and by reducing conflicts	9. Strengthening of legal bonds (PH1): arranging equity participation of first-tier suppliers in phase suppliers	(Majumdar et al., 2021)
	10. Market alternatives for capacity saturation (PH2): producing raw fabrics to stock for alternative markets to increase capacity saturation	(Huynh, 2022; Majumdar et al., 2021)

perspective on circular supply chain orchestration, and because it has been used and referenced by several subsequent studies in the CE literature. Moreover, Table 4 reports the challenges that have been found in the empirical study, based on the classification in Table 1, and matches the challenges with the response actions found in the cases. Each response is described in the following.

Standardization mechanisms aim at formulating and establishing industrial requirements (formal and informal) associated with CE (Parida et al., 2019). In the cases, institutional actions are adopted to tackle a challenge often mentioned by the CE literature, which regards the role of norms and regulations (Abdelmeguid et al., 2022; Dulia et al., 2021). Though a company cannot overcome this issue alone, the strong engagement to improve regulations by FT1 shows that actively carrying out lobbying actions is key to change regulations developed for a linear economic model in favour of a circular supply chain. This is part of a broader phenomenon experienced in the Prato district, concerning institutional actions that require the collaboration among companies (even competitors) and between companies and institutional actors, such as the Chamber of Commerce, to develop a common certification programme for the regenerated wool (Testa et al., 2017), as well as projects and festival launched by the local institutions to promote the image of circularity of the district and companies (Bressanelli et al., 2022). Institutional actions are often suggested by literature in the textile industry as powerful actions to overcome CE adoption challenges (Diabat et al., 2014; Saha et al., 2021), but literature neglected to highlight that these actions, instead of being carried out autonomously by single companies, are collective or orchestrated by a focal company, as exemplified by the FT1 case.

Nurturing mechanisms concern bearing early investments, developing new routines and processes and sharing core knowledge with partners (Parida et al., 2019). Several responses emerged in this domain. First, first tier suppliers finance the renovation of production equipment of the phase suppliers to have up-to-date technologies and reduce production costs to respond to economic and financial viability challenges, as exemplified by FT1. This is relevant because, due to market evolution, phase suppliers suffer from low selling prices and have not upgraded and digitized their production equipment since long time. Second, greater information exchange allows for the integration of supply chain processes, resulting in improved control, increased production capacity saturation and efficiency by phase suppliers, and skills upgrade, exemplified by FT1. Both long-term agreements and a greater information exchange in the supply chain allow tackling the variability challenge of pre- and post-consumer waste volumes, besides increasing supply chain coordination and integration. These actions have been widely discussed by previous literature in the textile industry (Cai and Choi, 2020; Franco, 2017; Huang et al., 2021; Jia et al., 2020; Majumdar et al., 2021). Third, vertical integration is another response emerged from the cases: first tier suppliers may vertically integrate production phases perceived as critical, or where they can exploit technical knowledge or other assets, while keeping a deverticalized approach to several other production processes and activities. This is the case of FT2 that vertically integrated the carbonization, tearing and fraying phases. Vertical integration improves demand planning and capacity utilization and exploit the availability of financial resources to invest in advanced equipment (the company owns carbonization and a water-shredding plants). Coupled with the coordination of phase suppliers for outsourced activities, this leads to greater operational efficiency and flexibility. This practice has been highlighted by previous studies about CE in the textile supply noted as mentioned in Section 2.3 (Cai and Choi, 2020; Franco, 2017; Huang et al., 2021; Jia et al., 2020). Fourth, traceability through digital technologies relates to the practices and tools for enhanced supply chain integration. It is achieved through digital technologies and increased information sharing to give visibility about material composition and traceability of processes (see cases FT1 and FT2). This is of utmost importance to guarantee product quality and respond to claims, and - since sustainability at environmental but also social levels in upper streams of the fashion supply chain is far from granted (Mejías et al., 2019) - also vital to back the image of a truly sustainable and circular supply chain, and differentiate from competitors (Sandvik and Stubbs, 2019). This is relevant because, although the role of Industry 4.0 technologies such as blockchain for implementing circular textile supply chains has been

Table 4
– Challenges and responses emerging from the empirical study.

Category	CE challenge (corresponding ID in Table 1)	Challenge description in the empirical study	Responses (reference to the case studies where it has been adopted)
Economic and financial viability	Higher investments and financial issues (1 + 2)	Due to market evolution regenerated carded wool phase suppliers, especially spinning mills, and the whole district suffers from low selling prices. Phase suppliers in particular are not profitable enough and have not upgraded (and digitized) their production equipment. Moreover, due to the uncertainty that characterizes the demand (volumes, continuity over time, …) making relationship-specific investments (towards first-tier suppliers) would expose phase suppliers to significant risk.	Financing the renovation of production equipment (FT1): financing the renovation and the digitization of production equipment of the phase suppliers to have up-to-date technologies and reduce production costs Market alternatives for capacity saturation (PH2): producing raw fabrics to stock for alternative markets increases cost efficiency, volumes and profitability Strengthening of legal bonds (PH1): an equity participation of a first-tier supplier in phase suppliers allow them to invest in up-to-date machinery, that in turn increases production efficiency and margins.
Market and competition	Know-how access (5)	Know-how protection: it is difficult to protect stylistic innovations and achieve differentiation, since most phase suppliers are shared among different first-tier suppliers.	Strengthening of legal bonds (PH1): equity participation by first-tier supplier in phase suppliers enforces protection against imitations
	Lower Brand Image (6)	Regenerated carded wool may be associated to an image as something “old” and low-priced.	Customer engagement and brand positioning (FASH) – Promoting local and sustainable clothing production as valuable aspects leads to an improved brand image of regenerated wool
Product characteristics	Fashion change (7)	Fast fashion promotes the use of synthetic fibres (against carded wool designed-to-last), which are lighter and cheaper. This led to reduction of the carded wool market share in the past. On the other hand, the low-quality materials and processes adopted to reduce costs harm their durability.	Customer engagement and brand positioning (FASH) – Promoting local and sustainable clothing production as valuable aspects leads to an increased value-for-money perception by customers
	Product complexity, mixed materials (8)	Garments not designed with regeneration as an objective, may not be discarded in the sorting and selection process (e.g., wool garments with gaskets in polyester). Composition of textile products makes them unsuitable for recycling, as in case of colour separation or the presence of plastics and metals	Co-design out waste (FASH): clothes are designed thinking at the sorting and regeneration processes
Standards and regulation	Regulations and standards (12)	Both pre- and post- consumer textiles are classified as ‘special waste’ instead of by-products or secondary raw materials, making it impossible to re-use production scraps (only recycling). The absence of an integrated policy framework to coordinate different stakeholders in the wool recycling negatively affects the industry. Legal-administrative constraints impose certification costs and additional complexity management burdens, especially to phase suppliers involved in the sorting process.	Institutional actions (FT2): lobbying at an institutional level to change laws that classify and regulate pre- and post-consumer textile waste, to remove constraints in the regeneration process and reduce the related bureaucracy costs.
Supply chain management	Volumes (13)	Variable (in time and mix) volumes of pre- and post-consumer waste for the sorting process. Highly seasonal demand challenges production capacity saturation and cost efficiency of phase suppliers Great deverticalization of the supply chain and fragmentation of the production process.	Strengthening of legal bonds (PH1): equity participation by first-tier supplier in phase suppliers increase coordination, early supplier involvement in design activities, reduced uncertainty on demand volumes and more efficient utilization of production capacity
	Supply chain coordination and integration (16)	Lack of effective communication, integration, and cooperation among supply chain members. Information exchange is limited to work orders, invoices and to the request for updates on the progress of jobs, with no involvement in design activities. Operational linkages are limited to the administrative process. Infrequent long-term agreements, with a prevailing opportunistic behaviour by the parties.	Greater information exchange (FT1): greater information exchange, facilitated by long-term agreement, leads to an enhanced integration at an operational level and allow for improved control, increased production capacity saturation and efficiency by phase suppliers, and skills upgrade Vertical integration (FT2): coupling own facilities at upper stages (improved planning, control and capacity saturation, ability to invest) of the supply chain and coordination of outsourced activities (orchestration, as FT1) achieves both operational efficiency and flexibility. Market alternatives for capacity saturation (PH2): producing raw fabrics to stock allow PH2 to improve cost efficiency (capacity saturation, levelled production), increasing volumes and improve planning (internal sales and marketing activities)
	Traceability (17)	Lack of traceability about materials composition and processes	Traceability through digital technologies (FT1, FT2): material composition and traceability of processes (e.g., through QR codes) to improve operations monitoring and support claims of a circular and sustainable supply chain
	Skill shortage (15)	Lack of skilled labour force that are needed to carry out some critical activities (e.g. sorting) that are mostly manual and require long-time experience. Societal changes and years of crisis have reduced the appeal of such jobs for the younger generations	Initiatives to increase attractiveness to younger generations to prevent the loss of skills (FT1): by setting up an Academy, involving students in design contexts or company visits to increase the attractiveness of the jobs related to the wool regeneration district, and favours the generational turnover. Customer engagement and brand positioning (FASH): increase the image and thus the attractiveness of the industry for potential employees
Users' behaviour	Willingness to pay (24)	End users may have a different willingness to pay for circular products, not perceiving their value. Regenerated carded wool suffers from low selling prices	Customer engagement and brand positioning (FASH): promoting sustainable and local production as valuable aspects and involving end customers as active parts in the take-back process, creates customer engagement that justifies a premium price

proposed by some studies in the textile industry (Franco, 2017; Huynh, 2022), its potential to overcome the related supply chain challenges has been overlooked to date. Fifth, initiatives aiming to increase attractiveness to younger generations is an orchestration mechanism addressing external stakeholders to the supply chain, to respond to skill shortage. In the Prato case, this especially concerns the ageing workforce carrying out the critical activities of *'cenciaioli'* and *'feltrinisti'*. Orchestrators respond by setting up Academies to collaborate with schools for increasing young people knowledge about professions in the wool regeneration process (FT1), as well as making marketing investment to improve the image of regenerated wool (FASH). Despite previous literature on textile industry highlighted the importance to preserve labour and workforce skills and competences (Kazancoglu et al., 2020), the operationalization of potential responses to address this challenges is lacking. Sixth, customer engagement and brand positioning improve the image of the industry as a whole in relation to sustainability and are being pursued by a number of companies (Huang et al., 2021; Saha et al., 2021), especially at the apparel producer level (Colucci and Vecchi, 2021; Khitous et al., 2022). For instance, FASH emphasizes the local production and consequent greater traceability of its process, the truly circular design, and promotes a take-back program thus directly involving the customer. Such actions also increase customers' willingness to pay a premium price for regenerated wool clothing, thus increasing supply chain margins. Lastly, product co-design that rules out waste (FASH) enables wool regeneration and thus a truly circular business, and responds to challenges in the 'product characteristics' dimension, and is in line with actions emerged in the studies by Cai and Choi (2020), Franco (2017), Huang et al. (2021), and Jia et al. (2020).

In the domain of negotiation mechanisms, the strengthening of legal bonds may consist of long-term agreements where supply contracts protect partners from opportunistic behaviour and strengthen trust, relational interdependencies (Parida et al., 2019) or even equity participations, as the one in a first-tier supplier by PH1. As shown in our empirical study, they provide phase suppliers with greater certainty about future volumes, improving production planning and capacity saturation. Coupled with direct financial support by the first-tier supplier, it encourages investments in up-to-date machinery, which, in turn, increases production efficiency and margins. Moreover, closer relationships with first-tier suppliers enable greater information sharing and integration of operational processes, ranging from administration to operations and product development. Also, an equity participation guarantees know-how protection since it discourages opportunistic behaviour by first-tier suppliers that would facilitate the imitation of solutions developed by a phase supplier. Legal bonds are a typical practice of supply chain integration (Cannon and Perreault, 1999) but they have been quite overlooked in the studies reviewed in Section 2 about circular supply chains in the textile industry. Lastly, exploring market alternatives for capacity saturation is another negotiation response that emerged from the multiple case study. In particular, phase suppliers add a make-to-stock production strategy to the typical make-to-order one, to achieve capacity saturation and improved planning and operational efficiency. This has proven effective in the production of the raw fabrics, as in the case of PH2: if coupled with direct marketing and sales presence to find new market niches, in fact, this response action leads to increased volumes and profitability.

5.2. Paper Contributions and Limitations

This research article provides three main contributions to research. First, our study advances knowledge in the domain of supply chain management for CE, contributing to knowledge accumulation on the emerging stream on circular supply chain orchestration. Resorting to seminal studies on these topics and integrating the resource orchestration view with the concepts of supply chain orchestration and CE we propose that circular supply chain orchestration can be defined as '*a set of deliberate actions by a focal firm that coordinates and manages diverse interests, ensures alignment among circular supply chain members, and structures, bundles and leverages resources to create circular value*', thus contributing to the systematization of this concept (see Section 2.4). Moreover, we adopt circular supply chain orchestration as a theoretical perspective to analyse challenges to CE implementation and response actions. CE challenges received significant attention in the literature but responses to overcome them have been generally analysed in isolation and with a single-firm perspective. Instead, through a supply chain orchestration perspective we can approach and interpret these actions systemically, as means to mobilize resources within the supply chain perspective to generate circular value.

Secondly, by systematizing response actions to CE challenges, this study contributes to the operationalization in the textile and fashion industries of the general CE orchestration mechanisms pointed out by the literature. In fact, frameworks have been proposed to classify and organize orchestration mechanisms in a CE (Asante et al., 2022; Parida et al., 2019; Trevisan et al., 2022), but an operationalization able to translate the proposed high-level directions into practical actions is currently lacking. We have identified the actions through the analysis of the CE literature in the textile industry and our case studies in the Prato district. We found that orchestration responses to the barriers should be activated in different domains, such as actions on the product design level or to engage customers and increasing the attractiveness of 'circular' products and brands, or lobbying actions to modify regulations. By structuring (in Table 3) circular supply chain actions around the three mechanisms of standardization, nurturing and negotiation (Parida et al., 2019), this article contributes to filling this gap, at least for the textile and fashion supply chains. Moreover, connecting the identified circular supply chain orchestration responses to the CE adoption challenges (Table 4), we shed light on the "why and how" specific actions are beneficial for overcoming the barriers found out in the literature. This is relevant especially considering that textile supply chains are long, fragmented and with an overwhelming presence of SMEs, endowed with limited financial and human resources.

Our empirical research also led to a third insight. Orchestrators focus on activating and integrating the different suppliers of outsourced activities, and this capability is recognized as a critical success factor for the supply chain, but it is generally associated to the fashion brand (Christopher et al., 2004). Through the case studies, we challenge this common view, showing that orchestration responses can be activated by other actors (generally SMEs) in the circular supply chain, in particular upstream actors. More specifically, we see that orchestration has been activated by first-tier suppliers (fabrics of yarn supply to a fashion brand, as in the case of FT1 and FT2), allowing to reduce uncertainty to phase suppliers, and supporting investments of second tier suppliers to manufacture circular products. When first-tier suppliers fail to orchestrate, we see that orchestration responses are activated by second tier suppliers (cases PH1 and PH2), especially through negotiation mechanisms. Our findings extend the focus beyond the one usually adopted in the textile and fashion supply chain literature and highlight the importance of strengthening the linkages among first and second tier suppliers.

This study, however, does not come without limitations. First, our contribution to the operationalization of circular supply chain orchestration mechanisms to respond to CE challenges has been carried out with a literature and field study focused solely on the textile and fashion industries. We therefore cannot at present claim for its generalization outside that industrial setting. Moreover, the empirical analysis relies on a limited number of cases, all located within the same geographical district and addressing a very specific supply chain, and although we analysed different roles in the supply chain (phase suppliers, first-tier suppliers, start-up fashion brands), we did not study all the parties of dyadic or network relationships simultaneously. Finally, through the adoption of a supply chain orchestration perspective we suggest that response actions which act in combination mutually reinforce each other, but we did not investigate in detail the synergetic effect of these actions.

6. Conclusions

Since a linear consumption model is no longer sustainable, the transition towards a CE is a priority for researchers, policymakers and practitioners. Such a transition is particularly needed for textile and fashion industries, being characterized by high resource consumption and environmental impact. The literature has already investigated the barriers hampering the shift towards a CE for the textile and fashion industries. By combining a literature review with a multiple case study involving five companies in the Prato regenerated wool district, this paper adopts a circular supply chain orchestration approach to address how these barriers can be faced. A list of potential responses to those challenges is first systematized, and then discussed in the light of the extant literature and the circular supply chain orchestration view. In particular the conceptual contribution of this paper can be summarized as follows. First, it advances knowledge in the domain of supply chain management for CE, contributing to theory development on circular supply chain orchestration by framing the concept and adopting it as a theoretical perspective to analyse challenges to CE implementation and response actions. Second, it contributes to the operationalization for the textile and fashion industries of the general CE orchestration mechanisms identified in the literature. Third, it shows that orchestration mechanisms can be activated by several actors upstream in the supply chain and not only by the fashion brand, thus extending the focus beyond the one usually adopted in the textile supply chain literature.

This study also provides an improved managerial understanding of CE challenges and responses. Companies in need of addressing barriers to circular supply chains in the textile and fashion industries may resort to the responses identified in this paper and the challenges they match, to inform their decisions. In particular, circular supply chain orchestrators may use the results of this research to design potential challenge-response mechanisms in the path towards CE.

Future research could focus on the generalization of the results outside the textile and fashion industries, by carrying out more case studies in other industrial settings. Moreover, future research could investigate the mutually reinforcing effects of deploying a set of orchestration actions simultaneously. Our research suggests that a systemic approach and the combined adoption of the abovementioned responses is more beneficial to overcome challenges than the effects of the ten responses taken individually, but this synergetic effect need to be further investigated. Lastly, while responses in the area of digitalization have been touched by the empirical study, we did not specifically focus on the role of digitalization in circular textile supply chains: investigating the mechanisms through which different digitalization actions provide benefits to overcome CE obstacles is another promising avenue for future research.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2022.11.020.

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