*sustainability*

MDPI

*Article*

# The Circular Economy and the Role of Technology in the Fashion Industry: A Comparison of Empirical Evidence

**Patrizia Gazzola [1,*], Enrica Pavione [1], Rainer Hillebrand [2], Vincenza Vota [3] and Rebecca Rosa [1]**

[1] Department of Economics, University of Insubria, 21100 Varese, Italy; enrica.pavione@uninsubria.it (E.P.); rebby.rosa.99@gmail.com (R.R.)
[2] Department of Business, Fulda University of Applied Sciences, 36037 Fulda, Germany; rainer.hillebrand@w.hs-fulda.de
[3] Department of Economics, University Carlo Cattaneo—LIUC, 21053 Castellanza, Italy; vvota@liuc.it
* Correspondence: patrizia.gazzola@uninsubria.it

**Abstract:** The present article analyses the theme of circularity in the fashion industry, with particular attention to the role of technology in favoring the adoption of circular economic models. The article explores the role of technology in supporting the circular economy in the fashion industry, focusing on the implementation of circular business models by three companies: SHEIN, Ralph Lauren, and Cotopaxi. The aim is to investigate the challenges and opportunities associated with the adoption of circular economy practices in an industry known for its environmental impact. The research highlights how technology, particularly software such as Materia MX, can facilitate streamlined supply chains, reduced waste, and optimized resource efficiency, thus, overcoming obstacles such as high investment costs and supply chain complexities. The case studies demonstrate how each company has integrated circular practices, such as recycling, reusing materials, and improving transparency through technologies such as AI, blockchain, and IoT, to promote sustainability. Thus, the study emphasizes the importance of technological innovation in enabling a more sustainable and circular future for the fashion industry while addressing challenges related to consumer awareness, regulatory pressures, and infrastructure. The results suggest that technology is a key factor in the fashion industry's transition to a circular economy, offering a competitive advantage and facilitating the achievement of environmental objectives.

**Keywords:** sustainability; fashion industry; circular economy; technology; business model



Academic Editors: Federico Lanzalonga, Andrei Bonamigo, Harnesh Makhija and Jun (Justin) Li

Received: 31 January 2025
Revised: 18 March 2025
Accepted: 25 March 2025
Published: 1 April 2025

**Citation:** Gazzola, P.; Pavione, E.; Hillebrand, R.; Vota, V.; Rosa, R. The Circular Economy and the Role of Technology in the Fashion Industry: A Comparison of Empirical Evidence. *Sustainability* **2025**, *17*, 3104. https://doi.org/10.3390/su17073104



## 1. Introduction

The fashion industry has undergone a period of substantial growth in recent decades, with worldwide sales reaching an estimated $1.94 trillion in 2023 [1,2]. However, this expansion has come at a significant environmental cost, with the industry becoming a major contributor to global pollution, including water waste, carbon emissions, and the overproduction of textiles that end up in landfills [3,4]. As sustainability becomes an increasingly pressing concern, the shift to a Circular Economy (CE) offers a promising solution to reduce the industry's environmental footprint. The concept of circularity in the fashion industry emphasizes the reuse, repair, and recycling of materials to extend the life cycle of products, ultimately promoting sustainability and reducing waste [3,4]. Despite the benefits of the circular economy, the transition from traditional linear production models remains challenging [5,6]. Fashion companies encounter various obstacles, including high investment costs, the complexity of reconfiguring supply chains, and consumers' lack of awareness regarding the environmental impact of their purchasing decisions. Moreover,

the integration of circular practices is frequently accompanied by the necessity to surmount substantial resistance within organizations, encompassing entrenched management practices and industry-wide competition propelled by the fast fashion model [7,8]. Notwithstanding, the industry is being propelled towards a circular model by several significant factors. There is an increasing demand from consumers for more sustainable and ethical practices, and many fashion brands are responding by adopting more environmentally conscious business models [7,8]. Technological advances, such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and machine learning (ML), are playing an increasingly critical role in enabling circularity. The utilization of these technologies has the capacity to optimize supply chain operations, enhance product traceability, and reduce resource wastage, thus, offering potential solutions to numerous barriers encountered by the industry in its pursuit of circularity [9,10]. This study explores the role of technology in promoting the circular economy in the fashion industry with a comparative analysis of three fashion companies, SHEIN, Ralph Lauren, and Cotopaxi, to ascertain how these organizations have integrated circular practices into their operations and to what extent technology has facilitated or hindered this transition. The study also examines the main barriers and drivers of circularity in the fashion industry, providing insights into the challenges and opportunities technology presents to promote more sustainable production models. To achieve these objectives, the research addresses the following key questions:

1. What are the main barriers and drivers of the circular economy in the fashion industry?
2. What is the role of technology in promoting circularity in the fashion industry?

By focusing on these questions, this paper aims to provide a comprehensive overview of the current state of circular economy practices in the fashion industry and to highlight the transformative potential of technological innovation in shaping a more sustainable future for the industry.

## 2. Literature Review

### *2.1. The Theoretical and Practical Background of the Circular Economy*

As previously mentioned in the introduction, the fashion industry has undergone significant expansion, yet this has come at a considerable environmental cost. Conventional methods of contemporary fashion garment production, such as dyeing and finishing, are characterized by high resource consumption and substantial environmental impact [11]. Consequently, these practices are being subjected to increasing scrutiny, as there is a growing imperative to transition towards more sustainable approaches [12]. In this context, the CE model emerges as a transformative alternative, promoting sustainability through material reduction, reuse, recycling, and recovery. This approach is predicated on the objectives of prolonging the utility of products and materials for as long as possible, whilst concomitantly minimizing waste and the environmental impact thereof [4,12]. It is now widely acknowledged as a pivotal transition from linear to circular systems, as these are recognized as efficacious in addressing the fashion industry's environmental footprint [13].

The circular economy in fashion is predicated on the redesign of processes, products and business models with the objective of minimizing waste, reducing raw material consumption and decreasing emissions associated with production and disposal [6,7]. However, this transition faces substantial obstacles, including high initial investments and the complexity of transforming supply chains [6,12]. Nevertheless, an increasing demand among consumers for ethical and sustainable products, coupled with the adoption of CE practices by companies, points to a shift towards more sustainable models [7,14]. Recent studies also highlight the integration of blockchain and generative AI in supporting these transitions. Blockchain, for example, facilitates enhanced traceability and transparency in supply chains, helping to ensure that products are sourced sustainably and recycled

efficiently [15]. Furthermore, the use of generative AI has proven to be pivotal in optimizing material use and product designs, making it easier for brands to adopt circular practices and reduce waste [16]. The "Cradle to Cradle" framework is a significant contributor to the theoretical basis of the circular economy. Developed by [17], the "Cradle to Cradle" concept is predicated on the idea that products and systems should be designed to be perpetually recycled through natural or industrial cycles without losing their value or quality. This framework emphasizes a regenerative approach, in which materials are continually reused and processes generate no waste. The approach advocates the design of products with the intention of their complete recyclability, reuse, or biodegradation at the end of their life cycle, thus, creating a closed loop that reduces the need for virgin resources. The "Cradle to Cradle" approach aligns with the circular economy by promoting systems that are restorative and regenerative by design. The principles of this framework are increasingly being adopted by fashion brands seeking to reduce their environmental footprint by designing garments that can be fully recycled or reused, thereby minimizing waste and extending the life cycle of materials. Incorporating this model into the fashion industry has the potential to facilitate the transition from a linear "take, make, dispose" system to a regenerative model where fashion products contribute to the continuous regeneration of resources rather than deplete them [17]. Integrating Cradle to Cradle into the fashion industry's circular economy practices provides a model for systemic change, advocating for innovative product designs and business models that support a closed-loop system.

### *2.2. Robust Secondary Data on Global Trends and the Fashion Industry*

The fashion industry's environmental impact is a matter of significant global concern, directly contributing to pollution [18]. The industry is responsible for 20% of water waste and 10% of carbon emissions worldwide [19]. Furthermore, 85% of textiles are landfilled annually, exacerbating waste and pollution issues [19]. The rise in fast fashion has intensified these problems. The term "fast fashion" refers to the rapid production of inexpensive, low-quality clothing designed to rapidly capture passing trends [20,21]. This model encourages overconsumption, with garments often discarded after only a few uses. The fashion industry is slowly recognizing its impact on the environment and is responding with increased efforts to adopt sustainable practices. The transition to a circular economy model is regarded as a potential solution to these challenges, with brands investigating recycling, material innovation, and sustainable sourcing strategies to minimize waste and pollution [1]. Moreover, consumer awareness and demand for environmentally friendly products are prompting companies to align their business models with sustainability principles [22].

### *2.3. Theoretical and Practical Evidence Regarding Circular Economy Business Models*

The adoption of circular economy business models in the fashion industry presents both opportunities and challenges, as theoretical contributions highlight. The potential of the circular economy to drive sustainability is evident in its promotion of resource efficiency, waste reduction, and minimization of environmental impact [4,12]. Practices associated with circular economy models, such as the recycling of materials and the designing of products for reuse, align with sustainability goals by promoting long-term resource efficiency. However, in practice, the transition to a circular fashion economy is fraught with challenges. A significant obstacle is the high investment costs required to implement circular practices [7,23]. Secondly, companies must navigate the intricacies of restructuring supply chains to align with circular processes, encompassing modifications in product design, material procurement, and production methodologies [24]. The absence of infrastructure,

particularly in regions with underdeveloped recycling and waste management systems, further exacerbates the adoption of circular practices [25].

Notwithstanding these challenges, there are compelling incentives for the adoption of circular business models. Consumer demand for sustainable products is increasing, and many consumers are placing greater emphasis on environmental considerations in their purchasing decisions [14,26]. Technological advances have also been identified as a crucial factor in enabling circularity [11,27]. Innovations such as blockchain, artificial intelligence and the Internet of Things have been shown to improve resource efficiency, optimize production processes and enhance product traceability. Blockchain technology, in particular, has proven to be an essential tool for improving supply chain sustainability by ensuring transparency and accountability in sourcing and recycling efforts [15]. Similarly, the integration of generative AI in fashion design and production has the potential to significantly reduce waste by optimizing material use and production timelines [16]. For instance, leading fashion brands are exploring the implementation of recycling programs, utilizing sustainable materials and promoting product longevity through repair and reconditioning programs [6,28]. These practices are not only in accordance with the principles of the circular economy but also provide a competitive advantage as consumers increasingly demand brands that prioritize environmental and ethical considerations [6,25,29].

In conclusion, while the transition to circular business models presents both theoretical and practical challenges, the growing emphasis on sustainability, technological advances, and consumer demand offers significant opportunities for the fashion industry to integrate circularity into its operations. The subsequent section will provide detailed examples of how companies are implementing these principles, drawing on industry case studies. Table 1 summarizes the main theoretical contributions, while Table 2 shows the strengths of the circular economy in the fashion sector.

**Table 1.** Barriers to the circular economy in the fashion industry.

| Barrier | Description | Source |
| --- | --- | --- |
| High investment costs | Implementing circular practices is not financially viable, for example, some recycling procedures require expensive technology | [5–7,11,23,25,29] |
| Complexity | Building a circular fashion chain and implementing circularity in product design requires changing and reallocating an organization's assets | [5,7,22,24,29] |
| Lack of infrastructure | Companies do not have the means to successfully implement circularity | [24,25,30] |
| Lack of consumer awareness | Throwing away culture and lack of interest and education | [5,7,8,11,23–25,29,30] |
| Lack of knowledge and skills | Recycling techniques require specific skills and know-how | [5–7,11,23,25,30] |
| Uncertainty about product quality | Skepticism about the value of products made through recycling processes | [7,8] |
| Higher prices | Circular products cost more thanks to the sustainable processes behind them | [8] |
| Insufficient government support | Lack of clear and common regulations and subsidies for companies implementing a circular model | [5–7,11,23,25,30] |
| Lack of collaboration | Network support along the supply chain is not optimal, especially in times of crisis | [6,8,22,25] |
| Competition | Slow fashion, which involves a reduction in production and consumption, is unable to compete with fast fashion | [5,30] |
| Credibility and trust | Difficulty in distinguishing companies committed to circularity from greenwashing campaigns, also due to the lack of tracking systems | [5,11,25] |
| Resistance to change | Managerial risk aversion and linear model supremacy | [5,11,23] |

Source: miscellaneous.

**Table 2.** Strengths for the circular economy in the fashion industry.

| Highlight | Description | Source |
| --- | --- | --- |
| Consumer awareness | Customers are pressuring companies to make ethical and environmental changes as they pay more attention to the effects on the planet and future generations | [5,7,8,11,22,25,28,30] |
| Resource efficiency | Waste and pollution are minimized | [28] |
| Cost savings | Recycling requires less energy than producing new clothes, thus, increasing profits | [5–7,25,28,30] |
| Technology and innovation | Constant research on how to implement circularity effectively (e.g., alternative fabrics) | [6,11,14,22,25,27,28] |
| Investments | Increase attention and incentives for the implementation of circular models | [26] |
| Standard Setting | Represent a model for other companies | [24] |
| Conformity | Compliance with regulations and policies, as well as pressure from different stakeholders | [5–7,22,24,25,28–30] |
| Corporate commitment | The highest levels set the direction of the company through strategic decision-making | [22,28] |
| Learning and organizational culture | Encourage education in circular economy practices, applying appropriate leadership styles | [8,25,28] |
| Scarcity of resources | Raw materials are limited, and businesses need ways to use them efficiently | [6,25,29] |
| Differentiation | Implementing circularity as a way to gain a competitive advantage over competitors | [6,29] |
| Reputation | Circular practices increase brand image and consumer loyalty | [6,28,29] |

Source: miscellaneous.

It is evident that some aspects are presented in both tables as opposites; this means that some of them represent strengths when they are present, while they represent barriers when they are missing. To give some examples, consumer awareness of environmental issues is a driver for circularity, but the lack of consumer awareness hinders its implementation; Similarly, the same happens at the company level, whether top management is committed to implementing circularity or is reluctant to change. Government support, adequate knowledge and skills, and innovative technological development are additional factors that can encourage or interfere with the deployment of circular models, depending on whether they are sufficient to support the implementation of circular practices.

Among the numerous categorizations of barriers and strengths that have been made by scholars, an important difference to be made is between the internal and external ones [6]. Internal factors refer to the direct choices of an organization, usually associated with activities over which the company has some control, such as the strategic direction and culture of the company; on the other hand, the external factors that a company faces reflect its operating environment, namely its customers, partners, and the government, which are independent of the company's control [31].

### *2.4. The Role of Technology in Fostering the Circular Economy*

As previously pointed out, in the fashion industry, traditional methods of production often involve resource-intensive procedures with a significant environmental impact, such as dyeing and finishing. As a result, the use of technology to promote supply chain circularity is becoming increasingly important. Without a doubt, technological development and innovation are the main enabling factors for the implementation of the circular model throughout the supply chain. The literature on the subject is very extensive [10,11,32–35]

and highlights the role that different technologies can play in supporting the fashion supply chain towards the transition to a circular model.

The approaches of Porter and Mintzberg, as well as those of Chatzinikolaou and Vlados, are distinguished by their divergent foci and methodologies, yet they are united by a shared interest in the analysis and strategic management of companies [36,37]. Michael Porter's approach is primarily oriented towards the analysis of the external environment and the manner in which companies can position themselves in the market to achieve a sustainable competitive advantage. His model is characterized by its strategic orientation, emphasizing differentiation and cost leadership. In frameworks such as the Business Model Canvas, Porter's approach finds particular expression in the value proposition block, where companies are required to clearly define their position in relation to their competitors [36]. In contrast, Mintzberg is recognized for his more dynamic perspective on strategy, conceptualizing it as a series of emerging models rather than a pre-planned course of action. His theory is based on the idea that strategy does not always have to be rational and formally planned but can emerge through practical experience and interaction with the environment [38]. In the context of the Business Model Canvas, Mintzberg's approach focuses on continuous adaptation and learning, suggesting that a company may need to rethink its value proposition, distribution channels, and key resources based on ever-changing market circumstances. Peters and Waterman's seminal work examined a series of successful companies, identifying their distinctive traits, such as customer orientation, decentralization, and continuous innovation. These factors can be translated into the Business Model Canvas in terms of customer relations and key activities. Customer centricity and the need to adapt to market demands are also common themes in Mintzberg's approach, as both emphasize the importance of a flexible, customer-centric strategy [39]. The approach proposed by Chatzinikolaou and Vlados (2022) [37] focuses on the analysis of strategic sustainability and the adoption of more modern business practices oriented towards a balance between innovation, operational efficiency and social responsibility. The authors emphasize the importance of integrating into the social and environmental community while pursuing profit objectives. This approach aligns with novel sustainable business concepts, which are of increasing relevance in contemporary contexts, as evidenced by the Business Model Canvas, particularly in the key partners and key activities blocks, where collaboration models and operations that favor sustainability and positive impact are defined [37].

More specifically, below are some examples of how technology can support the sector in question.

Internet of Things (IoT): This term refers to the capillary network of devices that permeates our daily lives. With the advent of more secure, faster, and easily installed connections, even in very small devices, countless computer-supported solutions have appeared, capable of simplifying or enhancing operations of all kinds. To function, these technologies require sensors for the input of audio, video, thermal, and process information [40]. These data are then processed, stored, and transmitted. Through these sensors and with the help of high-speed connections, all kinds of data can be collected, transforming this digital network into a digital sensory organism. In the fashion industry, real-time IoT-generated data on the condition, location, and usage of products and materials throughout the supply chain facilitates efficient asset and inventory management and better product lifecycle monitoring.

Blockchain technology is a technology belonging to the family of Distributed Ledgers, i.e., technologies that have in common the presence of a distributed ledger, for example, a database that does not reside on a single machine (PC or server) but is distributed over several nodes of the network, each containing a synchronized copy of the ledger itself [41].

The use of blockchain in the field of product traceability is undoubtedly a guarantee for the consumer, as it can guarantee a control system for food [42], medical products, textiles, etc., acting as an accessible but immutable record, offering a secure and transparent way to trace origins and certifications. It improves traceability and accountability, which are key to ensuring compliance with circular economy standards and building trust.

Artificial Intelligence (AI) and Machine Learning (ML): The advent of hardware with ever-increasing computing capabilities has made it possible to overcome the problem of timing and has paved the way for the statistical processing of otherwise useless data stores, including big data [43]. Statistical analysis and the creation of registers to manage complex algorithmic instructions have given rise to the era of AI, a software capable of analyzing prompts (user requests) and returning increasingly precise and elaborate results [44]. The data on which a model is trained describes the capabilities and behavior of AI, allowing it to act as an intermediary between the request and the enormous, otherwise unfathomable, amount of data from which to draw the answer. However, AI does not just return raw data, but processes it in form, meaning and specificity, sometimes leading to direct solutions to the problem, rather than the mere source from which to draw such information; this is exactly why these systems are said to mimic human intelligence and are, therefore, referred to as Artificial Intelligence. The more trained an AI is, the more competent it is in its subject, but it can still lack specificity, form, and other characteristics. This is where a subset of AI comes to the rescue: machine learning. While AI is concerned with exploiting the data in its possession to understand natural language, images, sounds and all other incoming information, ML is concerned with exploiting the latter, together with the response that will then be given to the user and their feedback, to learn new notions and to understand what is classified as more consistent and correct and what is reported as inaccurate or incorrect. Through ML, an AI is not meant to remain the same but will evolve with its users and the tasks that are submitted to it, bringing it closer to perfection in form, specificity, and content. Through artificial intelligence equipped with ML algorithms, companies can receive predictive data and corrective proposals and identify supply chain defects before they even manifest themselves explicitly. In the fashion industry, AI and machine learning algorithms can be used to analyze large amounts of data to optimize supply chain operations, forecast demand, and manage inventory. They facilitate decision-making processes related to material sourcing, product design, and waste management [43,44].

Specifically, SHEIN's utilization of AI has been found to be of significant value in the realm of inventory management. The employment of machine learning algorithms enables the company to make more precise demand predictions, thereby mitigating issues such as overproduction and waste. The AI system undertakes the processing of historical data to predict trends, ensuring the optimization of stock levels and the reduction in unsold stock that might otherwise result in waste. This contributes to the reduction in excess production and the promotion of the reuse of materials within the supply chain.

Conversely, the "Gear for Good" initiative by Cotopaxi employs artificial intelligence and data analysis to enhance the management of the product life cycle and promote circularity. Through the utilization of sensors to monitor product usage and condition, and by offering customers the option to return used equipment for repair or recycling, Cotopaxi is able to extend the lifespan of its products, thereby reducing waste and promoting reuse. The integration of data analytics into this program is instrumental in optimizing the reuse of materials, facilitating predictive maintenance, and identifying the necessity for refurbishment or reuse.

Advanced production technologies. Technologies such as 3D printing support the production of components on demand, allowing for customization and repair of products,

reducing the need for large inventories, and enabling the use of recycled materials in production.

Big Data: The term collects in a single definition all types of data that are so large that they cannot be processed by conventional systems and for which ad hoc systems have been designed. The examples shown highlight how technological innovation is causing ever greater revolutions in workflows, decision-making processes, business management and the optimization of production processes. The development of new technological tools is continuous and constant, and their diffusion has radically changed what can be defined as the normality of the management of production, storage, and sales chains [45,46].

As the industry approaches the so-called fourth industrial revolution, digital technologies are a crucial component in transforming production methods to address the industry's involvement in climate change. While emerging innovation could help companies meet demand and, at the same time, reduce their carbon footprint, implementing these solutions globally can present some challenges: lack of standardization, integration of these new systems, lack of skills, and related costs are some of them.

In addition, further investment in research and development is needed in order to develop new technologies that continue to improve the circularity of the fashion industry and contribute to achieving the urgent goal of decreasing its impact on the environment, reducing resource input, waste, emissions and energy use, but without sacrificing growth and profitability.

The emergence of these multiple needs has led to the birth of software capable of optimizing every single activity: ticketing software for pre- and post-sales support, shipment tracking software, production chain monitoring, statistical analysis, simplification of decision-making processes, customer management, and much more.

The trend that is emerging is not to install software for every need, as this would require many licenses with the relative economic cost, a lot of technical staff with the relative expense in terms of money and occupation of resources, the need to train many people for each individual software, and the possible incompatibility of data in the transition from one software to another. The solution comes instead in the form of multifunctional tools, capable of satisfying some, if not all, of the company's needs, while also optimizing data integration between the various modules and eliminating the limit on the number of tools that can be implemented. To make the initialization of these tools even faster and easier, the software houses that develop them are moving to a new software model that does not require minimum requirements on the company's systems and machines, for example, eliminating the expense related to the need to buy more powerful and modern PCs, and which does not require the intervention of a technician for installation. They are called SaaS (Software as a Service), and are complex tools available in the cloud that offer significant advantages including reduced operational and maintenance costs, increased proactivity of architecture scalability, optimized management of large volumes of data, and centralized and guaranteed synchronization of data [47].

In this study, Figure 1 illustrates the conceptual framework that represents how emerging technologies, such as AI, blockchain, and the IoT, are influencing circular economy practices in the fashion industry. The diagram highlights the connections between these technologies and key circular economy principles, such as reusing materials, reducing waste, and extending product lifecycles, thus, clarifying how these innovations contribute to sustainability and circular business models.

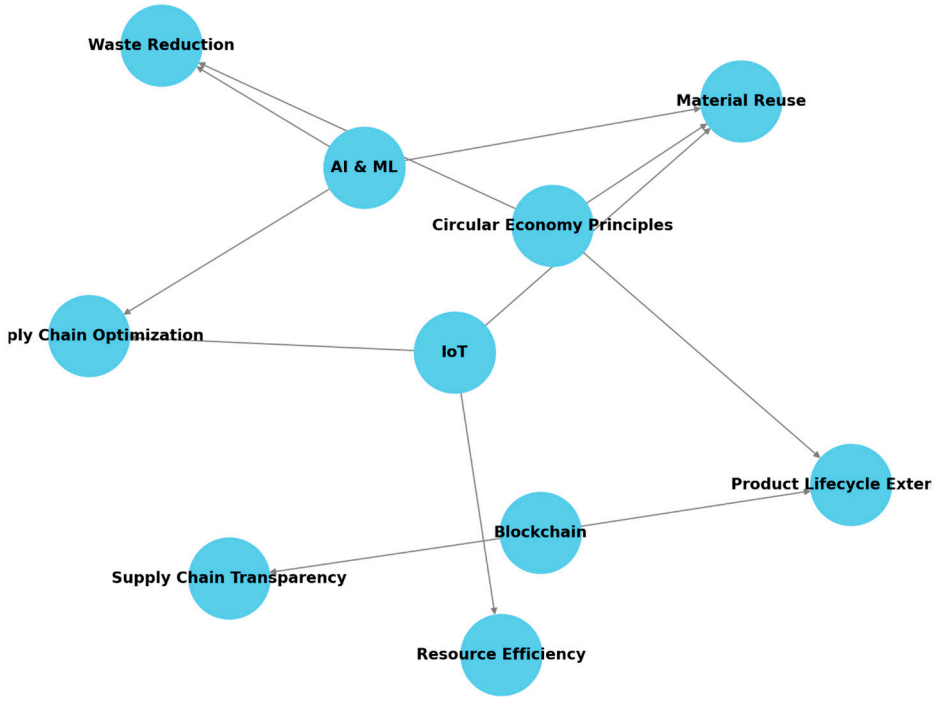


**Figure 1.** Conceptual framework for technology and circular economy in the fashion industry. Source: miscellaneous.

The present study draws from various interdisciplinary approaches to the concept of a circular economy (CE) in the fashion industry, as evidenced by the analysis of relevant literature. The theoretical framework that emerges from this analysis is founded on the following key concepts:

(1) Principles of the circular economy: based on a closed-loop system in which resources are reused, recycled, and restored, thereby reducing waste and environmental damage. Concepts such as "Cradle to Cradle" [48] and "Resource Efficiency" are fundamental in this case.

(2) Obstacles to circularity: Common challenges in adopting CE include high initial costs, supply chain management complexity, lack of infrastructure, and consumer awareness. These obstacles impact both small and large companies in the fashion industry. Literature on the subject posits that the overcoming of these obstacles can be achieved through technological advances, government policies, and corporate commitment [5,6].

(3) Circularity drivers: External and internal drivers encourage the adoption of CE, such as consumer demand for sustainable fashion, regulatory pressures, and resource scarcity [14]. In addition, technology can act as an important enabler of circular practices [10].

(4) The technological impact on the circular economy: Emerging technologies such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and machine learning offer practical solutions to improve transparency, optimize the use of resources, and facilitate recycling [11,32].

## 3. Methodology

This study uses the case study methodology developed in the social sciences [49,50]. This methodology is common not only in the social sciences, such as psychology, sociology, anthropology, and economics, but also in practice-oriented fields, such as environmental studies, social work, education, and business studies. Case study research excels at bringing

greater understanding to a complex problem or object and can add experience and strength to what is already known through previous research. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships.

In consideration of the aforementioned factors, this essay will examine three companies operating within the fashion industry: SHEIN, Ralph Lauren Corporation, and Cotopaxi. Despite their divergent market segments, these companies have garnered significant consumer attention due to their responses to the growing concerns surrounding the circular economy. On the demand side, consumers are increasingly demanding greater efficiency in resource utilization from companies. On the supply side, companies are recognizing the need to enhance resource efficiency [1,2].

The decision to analyze three case studies from companies with different business models—SHEIN, Ralph Lauren, and Cotopaxi—is motivated by the desire to explore how circular economy practices can be applied in different contexts within the fashion industry. These companies operate in different market segments: SHEIN in fast fashion, Ralph Lauren in the luxury sector and Cotopaxi in the sustainable outdoor clothing market [6,7]. This diversity enables us to illuminate the heterogeneity of circular adoption across different organizational types, thereby offering a comprehensive and diversified perspective on the sector as a whole. Moreover, the integration of innovative technologies by these companies to promote sustainability is a salient feature. This integration encompasses the use of software for stock management and material recovery, as well as the implementation of advanced recycling practices, including supply chain traceability [10,11]. The inclusion of these companies facilitates analysis of how technology, when adopted in divergent ways, can play a pivotal role in supporting the transition towards circular practices. Despite differences in business models and the challenges they face, all companies demonstrate a considerable commitment to adopting circular economy solutions, thus, demonstrating that even the most critical sectors, such as fast fashion, can evolve towards more sustainable practices [14]. This comparison facilitates a more profound comprehension of the factors that impede and facilitate the adoption of such models, and the role that emerging technologies can play in the success of these transitions. In order to ensure the reliability of the qualitative data collected from these case studies, triangulation methods were employed. This approach involved cross-referencing data from multiple sources, including company reports, interviews with industry experts, and publicly available information about the companies' sustainability practices. Additionally, the validation of sources was carried out by corroborating findings with secondary data from reputable industry reports and academic literature.

These steps were implemented to mitigate potential bias and enhance the robustness of the conclusions derived from the case studies.

Despite the divergent business models and challenges faced by these companies, a substantial commitment to adopting circular economy solutions is evident. An examination of these companies through the lens of the "Cradle to Cradle" theoretical framework illuminates their approach to design, emphasizing longevity, recyclability, and minimal environmental impact. This paper explores the integration of circular economy principles into the operations of these companies and assesses their success in achieving sustainability goals through the application of the "Cradle to Cradle" framework to case studies.

The present study has opted for a case study methodology, as outlined in the document, in order to test the aforementioned theoretical framework. The three companies selected for the study—SHEIN, Ralph Lauren, and Cotopaxi—offer contrasting approaches to CE adoption, based on their market segment, company size, and corporate culture [8,25].

### *3.1. SHEIN*

SHEIN is a global online fashion and lifestyle retailer, primarily known for its fast fashion clothing for women, men, and children, as well as a wide range of accessories, beauty products, shoes, and homewares [51].

The company is headquartered in China but operates worldwide, with a significant presence in the United States, Europe, and other regions. It operates on a direct-to-consumer business model, leveraging its extensive supply chain network in China to quickly produce and distribute fashion items at low costs. Key elements of its business model include the following [51]:

- Fast fashion: *SHEIN* is known for its ability to identify and react quickly to fashion trends, producing new designs and bringing them to the market in a matter of days or weeks.
- Affordable pricing: By maintaining control over its supply chain and using economies of scale, *SHEIN* offers products at competitive prices.
- Online-only retail: *SHEIN* primarily sells through its website and mobile app, which allows it to reach a global audience without the overhead costs associated with physical stores.
- Data-driven approach: The company uses data analytics to understand customer preferences and optimize inventory management, ensuring that they can meet demand without significant overproduction.

Despite its success, SHEIN has faced several controversies and criticisms regarding the ethics of its work [52,53]. The company has come under scrutiny for its labor practices, with allegations of low pay within its supply chain. Concerns have also been raised about the environmental impact of its fast fashion model, particularly with regard to waste, pollution, and other sustainability issues. Finally, SHEIN has been accused of copying designs by independent designers and established brands, with legal repercussions.

That is why *SHEIN* is actively working to implement sustainability and circularity within its operations through a strategic framework called evoluSHEIN Roadmap [54]. This plan is based on three main pillars: People, Planet, and Process, each of which addresses different sustainability challenges in the fashion industry.

Overall, this approach to sustainability and circularity involves a comprehensive set of initiatives aimed at reducing environmental impact, promoting ethical supply chain practices, and engaging both consumers and communities in more sustainable behaviors in order to "accelerating a journey towards a sustainable future accessible to all" [54].

In this section, we will discuss the barriers to CE adoption that SHEIN faces.

Firstly, SHEIN faces high investment costs. As a fast fashion brand, SHEIN's main challenge lies in the high costs associated with switching to a circular production model. The company's rapid production cycle and low-cost strategies have led to concerns about the financial viability of large-scale circular practices. Secondly, there is a lack of consumer awareness. Despite SHEIN's efforts to promote circularity, consumers remain largely unaware of the benefits of circular fashion, with a preference for low-cost, trendy items over sustainability. (3) Supply chain management complexity: SHEIN's extensive global supply chain presents challenges in implementing circular processes, due to the complexity of standardizing and managing diverse production systems.

In the contemporary business landscape, there are several factors that are propelling companies towards a circular model of operation. Firstly, there is an increasing consumer demand for sustainability. This has led to a growing demand for environmentally friendly fashion products, which has in turn compelled companies such as SHEIN to explore sustainable business practices. The growing awareness amongst consumers of the environmental impact of fast fashion has become a key motivation for brands to incorporate more sus-

tainable processes into their operations. Secondly, there is a corporate commitment to circularity. The company's EvoluSHEIN Roadmap, a strategy to promote circular economy initiatives, is a testament to its commitment to sustainability. This commitment is driving the company to find innovative ways to reduce waste and improve resource efficiency. Cost saving is another key factor. While high initial investments are a barrier, SHEIN recognizes the long-term cost benefits of reducing waste and optimizing resource use. Circular practices offer the potential to minimize raw material costs through reuse and recycling of textiles.

The role of technology in facilitating the transition is also crucial, as evidenced by SHEIN's partnerships with Queen of Raw and the implementation of Materia MX software. This software assists SHEIN in managing surplus fabrics, tracking inventory, and identifying opportunities to reuse materials in new collections. Consequently, Materia MX enables SHEIN to efficiently track excess materials while managing inventory and excess fabrics in real time, thereby minimizing waste. In addition, the software facilitates material recycling by aiding SHEIN in identifying dead stock that can be reused, thereby contributing to the company's circularity objectives.

### *3.2. Ralph Lauren*

Ralph Lauren Corporation is a recognized global leader in the design and distribution of high-quality lifestyle products [55]. The company, founded in 1967 by American fashion designer Ralph Lauren, has become synonymous with classic American style, offering a wide range of products that include clothing, accessories, home furnishings, and perfumes. Over the decades, Ralph Lauren has cultivated a brand that embodies a sophisticated and timeless lifestyle, characterized by a mix of tradition and modernity.

Ralph Lauren Corporation operates in several markets around the world with flagship stores in major cities, such as New York, Paris, and London, as well as a strong online presence. The brand's success is based on its ability to maintain a consistent image of luxury and quality while adapting to changing consumer preferences and trends. This adaptability has allowed Ralph Lauren to remain relevant in the fast-paced fashion industry, balancing its rich heritage with innovative marketing strategies and product offerings.

The company recognizes the importance of sustainability and circularity, to the point of having integrated these paradigms into its business model through a comprehensive strategy known as "Timeless by Design" [55], consisting of three main pillars: creating with intention, sustaining better lives, and protecting the environment. This approach focuses on creating products with lasting value while minimizing environmental impact throughout the product's lifecycle. The company is also committed to using 100% sustainably sourced materials for its key products by 2025. In addition to sourcing, the company also focuses on circularity, which is reflected in initiatives such as the "Ralph Lauren Vintage" program [56], which allows consumers to buy and sell used Ralph Lauren pieces. This program not only extends the life of the products but also reduces waste by keeping items out of landfills. Since 2022, a collaboration has also been underway with the international textile marketplace Queen of Raw to solve the problem of fabric waste in factories in China and Vietnam, two important supply nations, with the intention of expanding over time to other foreign nations. On another note, the company is also working to reduce its environmental footprint through various means. For example, Ralph Lauren aims to achieve net-zero greenhouse gas emissions by 2040, an ambitious goal that includes reducing emissions across the entire supply chain, as well as investing in renewable energy. In addition, the company is committed to reducing water and energy consumption in its manufacturing processes, particularly in areas such as dyeing and finishing, which are traditionally resource intensive. Additionally, Ralph Lauren's commitment to sustainability

is evident in its efforts to eliminate high-risk chemicals from its supply chain and to use more sustainable packaging materials. The company is working to ensure that all of its packaging is recyclable, reusable, or compostable by 2025.

In this section, the challenges associated with Ralph Lauren's adoption of CE will be examined. Firstly, there is the issue of high initial investments, particularly in new technologies and changes to the supply chain. However, the brand has been proactive in seeking funding and strategic partnerships to mitigate these costs. Secondly, the complexity of the supply chain is a concern, given Ralph Lauren's focus on luxury and the necessity of high-quality materials and workmanship. This makes it more difficult to implement circular processes without compromising product integrity. Ensuring circularity in such high-end products adds complexity. Thirdly, there is uncertainty about product quality: as a premium brand, Ralph Lauren is concerned with maintaining product quality, and the possibility that recycled materials could compromise this standard is an obstacle. On the other hand, the factors driving this company towards circularity are as follows: (1) Brand reputation and consumer loyalty: in fact, it has a strong brand image rooted in luxury and sustainability. The company's commitment to circularity is driven by the desire to align itself with growing consumer expectations regarding environmental responsibility. (2) Regulatory pressure is a key factor, with global regulations on waste reduction and sustainability tightening, motivating Ralph Lauren to adopt circular economy practices to comply with international standards. (3) Resource efficiency and cost savings are a key factor in implementing circular economy practices, with Ralph Lauren able to lower production costs in the long term by reusing materials and reducing waste. The role of technology in facilitating the transition is also important. Ralph Lauren uses Materia MX to track unused materials within its supply chain, making it easier to identify excess stock for reuse. This software allows the company to increase transparency, monitoring the flow of materials and ensuring that waste is minimized at every stage of the supply chain. It also improves resource efficiency by identifying opportunities for fabric recycling and reuse.

### *3.3. Cotopaxi*

Cotopaxi is an outdoor apparel company founded in 2014 by Davis Smith with a mission rooted in both sustainability and social impact [57]. The company's mission revolves around its Gear for Good Promise [57], which emphasizes creating products that are not only functional, but also produced ethically and sustainably. Cotopaxi is committed to using business as a force for positive change, with a particular focus on reducing poverty and promoting environmental sustainability.

For this reason, Cotopaxi's circularity practices are present in every aspect of its business model [57]. The company uses more than 96% non-virgin materials in its products, including recycled, reused, and responsibly sourced fabrics. For example, their Del Día Collection features one-of-a-kind packaging made entirely from repurposed fabrics, a practice that minimizes waste from other companies' production processes. In addition, a branch of the company, Cotopaxi Más Vida, gives high quality equipment another life, allowing customers to buy used items or exchange them, thus, endorsing responsible shopping habits.

Cotopaxi is also a certified B Corporation [58], which holds the company accountable for high standards of social and environmental performance, ensuring that its business practices have a positive impact on both people and the planet. In addition, Cotopaxi is a member of 1% for the Planet104, committing at least 1% of its annual turnover to environmental causes, notably through the Cotopaxi Foundation, which supports nonprofits that focus on healthcare, education, and livelihoods, particularly in Latin America, reflecting the founder's personal connection to the region.

In addressing the obstacles to the adoption of CE, a number of factors have been identified. Inadequate infrastructure is a primary concern. Cotopaxi, while demonstrating a commitment to sustainability, faces challenges related to the absence of adequate recycling infrastructure, particularly in the remote regions where some of its products are manufactured. Secondly, there is a lack of consumer awareness: despite the company's strong commitment to sustainability, Cotopaxi must continually educate consumers about the merits of circularity and its own sustainability practices. Thirdly, the company faces very high initial costs: although Cotopaxi prioritizes sustainability, the transition to a completely circular business model requires substantial investment in innovative technologies, materials, and processes.

Concerning the factors propelling CE, the following were identified: (1) Corporate social responsibility: Cotopaxi's mission is intricately intertwined with social impact and environmental sustainability. This profound sense of responsibility impels their endeavors to implement circular practices across their supply chain. (2) Resource scarcity: The company's utilization of non-virgin materials in the majority of its products is driven by the necessity to conserve resources and reduce reliance on raw materials. (3) Consumer demand for ethical fashion: Cotopaxi's customers place a high value on sustainability, further motivating the company to adopt circular practices to meet consumer expectations. (4) The role of technology in facilitating the transition: Materia MX, a software utilized by Cotopaxi, facilitates the tracking of surplus materials and the identification of opportunities for recycling or reuse of fabrics. This software enables the optimization of material use and the minimization of waste by identifying unused stock and reusing it in new collections, thereby ensuring an efficient use of resources. Additionally, Materia MX allows monitoring and reporting of the environmental impact of processes, enabling Cotopaxi to transparently report on its circularity efforts and to share these data with consumers, thereby fostering trust.

## 4. Results

The application of the theoretical framework of CE principles has yielded several key findings regarding the impact of technology, specifically Materia MX software, on the overcoming of barriers and the enhancement of drivers of circularity in the fashion industry. Each of the three companies—SHEIN, Ralph Lauren, and Cotopaxi—has made substantial progress in the adoption of circular practices with the assistance of Materia MX, thus, highlighting the transformative role of technology in advancing sustainability goals.

- Impact of technology on overcoming barriers

1. High Investment Costs: The use of Materia MX has allowed companies to overcome the challenge of high initial investment costs in the circular economy. While transitioning to a circular model often requires significant upfront investments, Materia MX provides an affordable and scalable solution that simplifies the process. Its SaaS architecture makes it accessible to companies of various sizes without the need for expensive infrastructure changes, thus, enabling small and large businesses alike to adopt circular practices. In accordance with the "Cradle to Cradle" framework, this approach promotes a transition from linear to circular production models, thereby significantly reducing resource consumption and waste generation from the outset.
2. Supply Chain Complexity: Materia MX plays a pivotal role in simplifying supply chain management for circular economy implementation. By centralizing inventory data and providing real-time updates on material flows, it helps companies streamline their operations and reduce complexities in managing waste and surplus materials. This has been particularly beneficial for large, global companies like SHEIN and Ralph Lauren, where supply chain visibility and coordination are critical. The software under

discussion provides transparency and traceability, which align with the "Cradle to Cradle" principles. These principles advocate material recovery and reuse as key components of sustainable product design and manufacturing.

3. Lack of Consumer Awareness: While consumer awareness remains a significant barrier, the transparency enabled by Materia MX helps companies better communicate their circular practices. Through the software's ability to track materials and provide real-time environmental impact reports, companies can offer clear evidence of their sustainability efforts. This enhanced transparency fosters consumer trust, thereby facilitating the management of concerns related to product quality and environmental impact. The concept of "Cradle to Cradle" underscores the significance of effective communication and active consumer engagement in facilitating the adoption of sustainable practices. It is imperative to ensure that these practices are comprehended and endorsed by the public.

- Impact of technology on enhancing drivers of circularity

1. Resource Efficiency: The inventory management and environmental impact modules of Materia MX have been shown to significantly enhance resource efficiency. By enabling companies to track surplus materials, the software helps to reduce waste and optimize the reuse of raw materials throughout the production process. This results in a reduction in the consumption of virgin materials, lowering the overall environmental footprint of companies. For instance, SHEIN recovered nearly 20,000 m of fabric in 2023, leading to significant savings in water and energy consumption. Similarly, Ralph Lauren saved approximately 11.8 tons of unused material, further enhancing resource utilization and reducing the demand for new materials. This directly contributes to the "Cradle to Cradle" goal of closing material loops, where resources are perpetually cycled and reused, eliminating the need for virgin inputs and minimizing environmental impact.
2. Cost Savings: Materia MX directly contributes to cost savings by enabling companies to monetize deadstock. The software facilitates the sale, reuse, or recycling of these materials through integrated e-commerce platforms or specialized recycling partners (Materia MX, 2023). This process not only generates additional revenue but also minimizes the costs associated with waste disposal and material overproduction. SHEIN's use of the software to create the SHEIN X Rescued Collection illustrates how circularity can become a profitable business model (ibid). The utilization of reclaimed fabrics by SHEIN serves to reduce the demand for new raw materials and concomitantly reduce production costs, whilst simultaneously offering customers a selection of sustainable fashion options. This approach is consistent with the "Cradle to Cradle" philosophy, which involves the transformation of waste into value by repurposing discarded materials into products that retain their value through reuse.
3. Corporate commitment and consumer loyalty: The incorporation of Materia MX serves to reinforce each company's commitment to sustainability, thereby directly aligning with their corporate social responsibility objectives. The capacity to track and report on environmental impacts assists companies such as Cotopaxi in aligning their practices with consumer expectations for ethical and sustainable brands. This contributes to enhanced brand reputation and loyalty, as consumers increasingly prefer brands that actively contribute to circular economies. In Cotopaxi's case, the software facilitated the identification and reintegration of surplus materials, enabling the company to divert a significant amount of waste from landfills and reduce its environmental footprint. "Cradle to Cradle" emphasizes how sustainability practices that enhance brand loyalty also serve as a competitive advantage, fostering long-term customer relationships built on shared values.

- The broader impact of Materia MX on circular economy practices

The Materia MX software is not merely a tool for the management of resources; it signifies a paradigm shift in the manner in which fashion companies approach circularity. Its integration of Machine Learning (ML) and blockchain technologies enhances decision-making processes and compliance with industry regulations. The software's capacity to analyze vast quantities of data, including inventory levels, material conditions, and environmental impact, enables companies to optimize their operations on a continuous basis. In accordance with the "Cradle to Cradle" philosophy, this technology facilitates the design of systems in which products undergo continuous recycling, encompassing not only material recovery but also efficiency and sustainability metrics. By integrating machine learning and blockchain technology, Materia MX ensures that all phases of the product lifecycle are optimized for minimal waste and maximum reuse.

The utilization of blockchain technology ensures transparency and traceability throughout the supply chain, thereby providing an immutable record of transactions that fosters trust among stakeholders. Machine learning further enhances the accuracy of environmental impact assessments by continuously refining its algorithms based on real-time data, thus, assisting companies in optimizing their processes to maximize efficiency and sustainability. The findings from the three companies underscore that Materia MX has already made substantial progress towards achieving circularity in the fashion industry.

This technological innovation is a key enabler of the "Cradle to Cradle" vision, creating a circular system where materials are constantly regenerated, thereby reducing the reliance on finite resources. SHEIN, Ralph Lauren, and Cotopaxi have each demonstrated how technology can effectively reduce waste, improve resource efficiency, and increase the reuse of materials. The potential for these companies to scale their circular practices is immense, with Materia MX acting as a catalyst for further integration of circular economy principles into their business models. SHEIN has the potential to reuse up to one million meters of surplus fabric, thereby significantly lowering its carbon footprint and resource consumption. Ralph Lauren is working to expand its use of Materia MX to more regions, with the aim of reducing waste in key manufacturing areas. Cotopaxi has successfully streamlined its supply chain, thereby contributing to its sustainability goals while creating products with a smaller environmental footprint.

In conclusion, the integration of Materia MX software has proven to be an effective solution in addressing the barriers and enhancing the drivers of circularity in the fashion industry. It offers a practical, scalable, and innovative approach to managing resources, reducing waste, and ensuring transparency. The success of this collaboration between Queen of Raw and fashion companies sets a model for others in the industry, demonstrating that technology not only benefits environmental sustainability but also creates new business opportunities and strengthens consumer trust.

*Technology Support Across the Three Companies*

One of the elements that unites the three companies considered is the use of specific software capable of optimizing every single activity in the value chain, in the direction of circularity. Specifically, the Materia MX software, created by the company Queen of Raw [59] is a tool for "Reusing, Reselling, and Recycling" and represents a virtuous and innovative example of the aforementioned multifunctional software based on SaaS. Queen of Raw's founder, Stephanie Benedetto, invented a way to turn pollution into profit by creating an online marketplace for buying and selling leftover fabrics. Simply put, software is used to balance supply chain profitability and circularity in the simplest way possible: "brands don't have to worry about anything. We take care of everything for them, from

finding buyers for their deadstock fabric to all payments and logistics. We really try to make it fast, easy and cheap, so that anyone is able to participate in our solution" [60].

In reality, its architecture is relatively simple, being an automation and integration middleware. Its main modules are inventory management, dead stock monetization, and environmental impact analysis and reporting. Thanks to the integration of modules through middleware, it is possible, for example, to use inventory management data for the monetization of dead stock and, through data on these sales, to obtain analysis on the reduction in environmental impact. However, these integrations can be very complex and prone to human error. This is where the automation functionality comes into play, freeing operators from the heaviest tasks, ensuring a high-quality standard and a reduction in resource occupation times. While highly functional software can already be achieved in this way, the technologies generated by innovation can multiply efficiency and increase compliance with industry regulations; this is the case of machine learning and blockchain algorithms.

- Inventory management: The inventory management module leverages a centralized cloud-based database to quickly provide consistent, up-to-date data in real-time using load balancers. The application of this tool allows you to optimize the flows of raw materials and products at all stages of the supply chain. By processing these data, companies can decide whether to reuse these materials internally and where. Although it is not part of the inventory management module, there is an auxiliary module for managing traceability along the supply and production chain. The purpose of the latter is to keep the chain situation and the condition of the materials always up to date. To ensure transparency, regulatory compliance, and communication with stakeholders, the Materia MX software uses blockchain technology, providing the company with a record of transactions. This is an example of how one can achieve a significantly better result than competing companies simply by using modern technology with wider potential. This approach distinguishes it from other industry competitors by facilitating enhanced transparency and the capacity to trace the trajectory of materials, thereby enabling the substantiation of sustainability assertions in a manner that aligns with the mounting demand for accountability within the fashion sector.
- Monetization of dead stock: With the data from the inventory management module, it is also possible to monetize what would otherwise only represent a maintenance expense. The destination of these materials can be, as mentioned, internal, but it can also be external; By exploiting the potential of software, it is possible to sell it on the market through integrated e-commerce channels or recycle it through specialized partners. In fact, Materia MX also acts as an intermediary between inventory and resale, recycling, and charity businesses. Ad hoc automations will, thus, make it possible to activate specific shipping procedures for items that exceed certain inventory thresholds based on company choices or sorting on multiple destinations with the help of AI.
- Analysis environmental impact and reporting: Using AI algorithms, especially when enhanced by machine learning, it is possible to leverage the data acquired from all sources (inventory, sales, stock management) to perform detailed and continuously updated analysis through automations that inform these algorithms of the presence of new data whenever there is a change in the database or related modules. These reports can be the most effective tools available to managers to support decision-making and planning activities. In addition, environmental reports and analyses can be used to publicize one's commitment and achievements in the circular economy, increasing one's popularity and promoting the choice of one's products over those of competitors. These sophisticated environmental assessments also reflect a broader trend in which companies are increasingly recognizing the importance of ESG metrics, something that

is becoming central to consumer choice in the fashion industry. These environmental impact assessment statistics can be very accurate thanks to the additional data that the software can calculate and track, such as water use, $CO_2$ emissions, and chemical waste. This analysis not only leads to a better understanding of the results obtained and the possible paths forward for a company but also allows the optimization of internal software processes through machine learning instruction, resulting in flow adjustments and increased efficiency.

The data collection and management environment can be defined as an Enterprise Resource Planning (ERP) system [61] which operates in a complementary manner with a Business Intelligence (BI) system [62], which is a set of processes and tools designed to improve the quality of business decisions by providing accurate, timely, and relevant data. While ERP deals with the more managerial side of data, BI serves as a tool for processing and producing customized reports. Each of these two systems makes use of one or more modules and technologies and does not represent a single tool, but rather is the result of the operation of several systems. Considering this technical premise, it would be reductive to refer to the Materia MX software as a simple management software, but instead its broader structure should be considered.

Therefore, this highly specialized software, which makes use of the best available technology, has already shown how much the very concept of the circular economy can change when applied to companies, making it not only a social, environmental, and moral advantage, but also a valid opportunity to reduce costs and even increase turnover. This is exemplified by the adaptation of such technologies to diverse organizational needs, as evidenced by the examples of SHEIN, Ralph Lauren, and Cotopaxi, despite their differing business models and market segments. The scalability of such technologies according to company size and market positioning is also demonstrated.

This is evidenced by the three companies considered in this study, which use the software in question in different ways, achieving significant results on the circularity front. The disparate approaches of the aforementioned entities underscore the adaptability of the technology in question, while concomitantly emphasizing the necessity for bespoke strategies that are contingent upon the specific business model. While Shein's focus lies in the domain of fast fashion, Ralph Lauren's emphasis is on high-end, timeless designs, and Cotopaxi integrates circularity into its overarching mission of responsible manufacturing.

First, *SHEIN* has taken significant steps to enhance its efforts towards a circular economy, through its partnership with Queen of Raw, which began in 2022, notably using Materia MX software. This collaboration is integral to *SHEIN*'s broader goal of becoming a leader in the reuse of excess materials from the fashion industry and advancing the circular economy, which fits perfectly into its on-demand business model.

One of the key achievements of this partnership is the launch of the SHEIN X Rescued Collection, which features garments made from reclaimed fabrics sourced from Materia MX. It is essential that they are made by suppliers who have achieved a high verification of social and environmental compliance through third-party audits and that at least 30% of the materials used must be recycled, such as recycled polyester and forest-safe viscose, or stored dead stock. This particular collection is designed to transform high-quality materials, which would otherwise go to waste, into new fashion items available to a global audience. In this way, *SHEIN* not only reduces textile waste but also conserves valuable resources, such as water and energy, thus minimizing the overall environmental impact. As a result, *SHEIN* was able to recover 19,927 m of tissue in 2023, based on the software's impact measurement [59]. This corresponds to a reduction in the amount of water (41.08 million gallons) and chemicals used (3051 kg), as well as carbon dioxide (28.94 tons) that would have been produced if these materials had been produced from the start. Ultimately,

the Materia MX software plays a crucial role in enabling SHEIN to identify, source, and integrate other brands' surplus fabrics into their manufacturing processes. This approach aligns with SHEIN's long-term sustainability goals, including its commitment to World Circular Textile Day, which calls for a fully circular textile industry by 2050 [51,63]. Thanks to this effort, SHEIN has the potential to reuse up to one million meters of surplus fabric, significantly reducing the need for new raw materials and lowering its carbon footprint. In comparison, Ralph Lauren's strategy employs a comparable technological approach, yet places greater emphasis on the creation of enduring products that can be resold or repurposed. Conversely, Cotopaxi utilizes a circularity approach as a reflection of its overarching sustainability mission. These disparities highlight the capacity of companies to adapt the same technological solution to align with their distinct business models and market segments.

Ralph Lauren Corporation also implemented Materia MX in 2022 to identify, track, and manage excess and unused materials within its global supply chain. Through the use of this software, Ralph Lauren has successfully saved approximately 11.8 tons of unused material in major manufacturing regions, such as China and Vietnam, and is working to expand this practice to other countries [59]. This effort has not only helped to significantly reduce waste, but has also preserved valuable natural resources, such as water and energy, that would have been needed to produce new materials. In addition, the initiative has helped reduce the overall environmental footprint of its supply chain.

Additionally, the implementation of Materia MX has improved Ralph Lauren's supply chain transparency, allowing the company to better monitor and manage its assets. This is all part of Ralph Lauren's broader commitment to sustainable practices, as outlined in its 2023 Global Citizenship and Sustainability Report. The company's partnership with Queen of Raw exemplifies its dedication to integrating innovative technologies into its operations to drive sustainability and create a positive environmental impact.

In a similar vein, Cotopaxi began using Materia MX in 2024 to better manage and reuse excess materials in its supply chain. The software allowed Cotopaxi to identify and track excess stock, including deadstock fabrics and materials that would otherwise have been discarded. By reintegrating these materials into its production processes, the company has been able to reduce waste and improve the sustainability of its product lines. In fact, through the use of Materia MX, Cotopaxi has managed to divert a significant amount of waste from landfills, reusing these excess materials in new products.

This effort aligns with Cotopaxi's mission to create "Gear for Good", emphasizing responsible and sustainable manufacturing practices. In addition, this software has also helped Cotopaxi streamline its supply chain operations, resulting in more efficient use of resources and a reduced environmental footprint of the company. Cotopaxi's Impact Report 2023 highlights these achievements as part of the company's broader sustainability and circularity goals.

Overall, the integration of Materia MX represents a significant step towards integrating sustainability into business models, demonstrating a commitment to reducing waste, promoting transparency, and driving change towards a more circular economy, while maintaining high production standards and making profits. This integration demonstrates that, while the core technology is similar, the application and focus can vary, reflecting the distinct strategies and goals of each company.

In addition to its environmental benefits, this initiative creates leaders in the circular fashion industry, offering a model for other companies looking to adopt similar practices. The success of this collaboration underscores the innovation behind Queen of Raw's technology and its potential to drive meaningful change within the industry, pursuing their

mission to "help companies minimize waste [. . .], while changing the way companies think about waste" [64].

As illustrated in Table 3, a comparative analysis of the three companies' circular economy strategies reveals a range of approaches to transitioning to a circular model. This analysis also highlights the challenges encountered and the results obtained by each company. The study offers a comprehensive overview of the strategies employed by SHEIN, Ralph Lauren, and Cotopaxi, as well as the impact of the technologies implemented on enhancing resource efficiency and overall sustainability.

**Table 3.** Comparative overview of circular economy strategies for SHEIN, Ralph Lauren, and Cotopaxi.

| Company | Circular Economy Strategies | Challenges | Outcomes |
|---|---|---|---|
| SHEIN | Adoption of AI for inventory management to reduce waste | High investment costs in circular practices | Recovered 19,927 m of fabric (2023) |
| | Collaboration with Queen of Raw and Materia MX for fabric recovery and recycling | Consumer awareness about sustainability | Reduced water usage by 41.08 million gallons |
| | Fast-fashion model with increasing emphasis on material reuse and recycling | Complexity in restructuring supply chains | Reduced $CO_2$ emissions by 28.94 tons |
| Ralph Lauren | Use of Materia MX to track and manage unused materials | High initial investment costs | Saved 11.8 tons of unused material |
| | "Timeless by Design" strategy focusing on creating lasting products | Maintaining high product quality while using recycled materials | Increased transparency in supply chain with Materia MX |
| | Vintage program for resale and repurposing garments | Complexity of integrating circularity in a luxury brand | Sustainable sourcing of materials aiming for 100% by 2025 |
| Cotopaxi | Utilization of non-virgin materials, including recycled and repurposed fabrics | Inadequate recycling infrastructure in some production regions | Increased use of recycled materials (96%) |
| | "Gear for Good" program: buying and selling used items | Lack of consumer awareness about circularity | Reduced environmental footprint by diverting waste from landfills |
| | Membership in 1% for the Planet, investing in sustainability initiatives | High costs of implementing circular practices and technology adoption | Streamlined supply chain leading to improved resource efficiency |

Source: miscellaneous.

## 5. Discussion

This study has analyzed the adoption of circular economy (CE) practices by three fashion companies: SHEIN, Ralph Lauren, and Cotopaxi. The tables presented in this section provide a comprehensive analysis of the primary obstacles and drivers in the adoption of circular economy practices by the companies under scrutiny: Shein, Ralph Lauren, and Cotopaxi. The tables also explore the potential influence of technology, specifically the Materia MX software, on these factors (Tables 4 and 5). This information is crucial for comprehending how technology not only addresses challenges but also fosters the adoption and expansion of circular practices, particularly within the fashion industry.

**Table 4.** The impact of technology on barriers to the circular economy.

| Barrier | The Impact of Technology | Possible Outcome |
|---|---|---|
| High investment costs | Negative | Upfront costs are required to implement the technology |
| Complexity | Negative | Difficulties especially in the construction phase |
| Lack of infrastructure | - | No assessable impact |
| Lack of consumer awareness | - | No assessable impact |
| Lack of knowledge and skills | Positive | Knowledge and skills become requirements |
| Uncertainty about product quality | - | No assessable impact |
| Higher prices | - | No assessable impact |
| Insufficient government support | - | No assessable impact |
| Lack of collaboration | Positive | Collaboration made easier |
| Competition | Positive | Technology is a source of competitive advantage |
| Credibility and trust | - | No assessable impact |
| Resistance to change | Positive | Innovation means constant change |

Source: our own elaboration.

**Table 5.** The impact of technology on the drivers of the circular economy.

| Driver | The Impact of Technology | Possible Outcome |
|---|---|---|
| Consumer awareness | - | No assessable impact |
| Resource efficiency | Positive | Efficiency would be easier to achieve |
| Cost savings | Positive | Operating costs reflect the level of efficiency achieved |
| Investments | Negative | Implementation of technological needs |
| | | Large investments |
| Standard Setting | Positive | Standards are constantly renewed |
| Conformity | Positive | Compliance would become easier with the help of technology |
| Corporate commitment | - | No assessable impact |
| Learning and organizational culture | Positive | Organizational culture must align and keep pace with innovations |
| Scarcity of resources | Positive | Access to secondary raw materials |
| Differentiation | Positive | Innovation causes significant differences between competitors |
| Reputation | - | No assessable impact |

Source: our own elaboration.

Considering the obstacles to implementing a circular economy model in the fashion industry, the analysis found that SHEIN, Ralph Lauren Corporation, and Cotopaxi seem to face few challenges, and this is likely due to their size, competitive position, and significant market share. For this reason, the lack of infrastructure and the competition represented in Table 1 as barriers do not represent an obstacle for the companies considered. It is also true that some recognized barriers have ceased to be an obstacle with the introduction of the Materia MX software: in particular, the factors “high investment costs” and “complexity”

do not play a relevant role because the software has been made to be intuitive and accessible to all types of companies. The "lack of collaboration" is also an aspect that has been made much easier to achieve through the use of software. This highlights the crucial role of technology in supporting companies towards a conscious path of transition towards new production models centered on circularity. In this context, the application of the "Cradle to Cradle" framework becomes a fundamental point of reference for the analysis of the results. This model focuses on the design of products and systems that can be continuously reused without creating waste. Rather than merely reducing the damage caused by a linear system, the "Cradle to Cradle" approach promotes the continuous cycle of materials and resources, creating systems that are regenerative for nature and the economy. Integrating this approach with the circular economy practices adopted by the companies analyzed demonstrates that the adoption of technologies such as Materia MX software not only reduces waste but also encourages the reuse and regeneration of materials. This framework facilitates the interpretation of the results obtained as sustainable practices that contribute to a closed system of materials, where value is preserved through closed cycles and ecologically circular production processes.

On the other hand, "lack of customer awareness", "uncertainty about product quality" and, in particular for SHEIN, "credibility and trust", represent major challenges in their journey to disclose their commitment and achievements in terms of sustainability and circularity in a credible way. The "Cradle to Cradle" framework under discussion here emphasizes transparency and information as essential tools for gaining consumer trust. It is vital for customers to be aware of the environmental benefits of circular practices, such as the reuse of materials and the reduction in waste, if change is to be supported.

Similarly, when considering the factors that led to the implementation of a circular economy model in the fashion industry, SHEIN, Ralph Lauren Corporation, and Cotopaxi can share several common motivations: consumer awareness and sensitivity to the issue, resource efficiency by minimizing waste, cost savings by reducing the amount of raw materials, corporate commitment, learning and organizational culture, and differentiation from the competition to gain an edge and build a good reputation are all excellent reasons why these companies have decided to invest seriously and continuously in sustainability and circularity. However, what emerged from the analysis is that the drivers of technology and innovation can play a crucial role in making a difference in the level of results obtained in terms of circularity. The use of technologies that support the "Cradle to Cradle" model promotes a regenerative production model, where the value of materials is maintained throughout the production cycle and are not wasted, as well as enabling resource efficiency.

In fact, technological innovation is increasingly going hand in hand with great revolutions in workflows, decision-making processes, business management, and the optimization of production processes. The development of new technological tools is continuous and constant, and their diffusion has radically changed what can be defined as the normality of the management of production, storage, and sales chains.

While one can agree on the significant benefit of using new technologies, one must also consider the negative side effect of this: a company that is unable or uninterested in working on the implementation of new tools will fall behind its competitors, see its reputation deteriorate, and the complexities of complying with new regulations increase. The "Cradle to Cradle" framework shows how, by embracing technological innovation, companies can not only reduce waste and resource consumption but also regenerate value at every stage of the production cycle. Technological innovation continues its race and does not wait for companies to catch up, imposing a fast pace that is difficult to ignore, otherwise a company will lose its position on the market, that is to say that technology and innovation certainly represent a driver for sustainability and, above all, circularity. A prime

example is the Material MX software for the reuse of excess inventory, made precisely to be user-friendly and adaptable to all types of organizations. Even if a certain degree of education and skills is necessary to work with any technology, the lack of it becomes a substantial barrier against circularity, hindering the very survival of a company.

In addition, technology can not only be an obstacle or driver in itself for a company, but it can also have a significant influence on other factors; based on the cases examined, Tables 4 and 5 outline the possible magnitude of the impact that the technology could have on the elements that have been classified as barriers and drivers for the implementation of the circular economy. While some of them have evidently not been affected by technology implementation, it is likely that most of the obstacles and factors can be enhanced by technology, both positively and negatively from a business perspective.

The key themes we address include the barriers to circularity, the drivers pushing companies towards adopting circular practices, and the transformative role of technology in overcoming challenges and enhancing opportunities. The present study identifies several obstacles to the adoption of the circular economy, in line with existing research on the challenges of the circular economy in the fashion industry [5,6]. These obstacles include high investment costs, supply chain complexity and lack of consumer awareness. The case studies in this research reflect these challenges but also illustrate how Materia MX technology has helped to overcome them. Secondly, with regard to the high investment costs, the literature suggests that the upfront costs of adopting circular economy practices can be prohibitive, particularly for large companies with complex global supply chains [6]. However, the present study demonstrates that the integration capacity of certain software technologies reduces the need for significant infrastructural investment, which is in line with the findings of Monyaki and Cilliers (2023) [7] that technology can help mitigate high upfront costs. In contrast to the intricacies of the supply chain, the management of circular supply chains is frequently characterized by complexity and the utilization of substantial resources [5,24]. Consequently, software such as Materia MX, by furnishing real-time data on inventory and materials, facilitates streamlined operations and enhances supply chain transparency. This finding aligns with the conclusions of Akram et al. (2024) [9], who underscore the pivotal role of technology in the streamlining of intricate circular supply networks. In the context of the fashion industry, there is a growing consumer awareness, which poses a significant challenge [14]. However, Materia MX software facilitates the provision of transparent data on circular practices, fostering consumer trust and raising awareness about the sustainability of products. This technological transparency is consistent with the research of Alves et al. (2022) [10], which identifies transparency as a key element in promoting sustainability.

In conclusion, all three companies examined revealed that the introduction of technology and innovation, such as Materia MX software, brings more benefits than problems to each organization, highlighting once again the crucial position of technological advancements in the path and aspiration to become circular.

## 6. Conclusions

This work aims to make significant contributions to the literature on circular economies, strategic management, and business models in the fashion industry, and it seeks to integrate all three areas. The manuscript focuses on understanding how technology, specifically Materia MX software, can enable fashion companies to adopt circular economy practices, contributing to sustainability in the industry.

The sector in question is facing increasing scrutiny of its environmental impact, and with increased awareness of climate change and resource depletion, circularity, along with sustainability, has become a crucial topic within the industry.

The shift to circular practices is driven by both consumer demand and increasing regulatory pressures. Consumers are increasingly looking for transparency and accountability from brands, preferring those that demonstrate a commitment to environmental stewardship and social responsibility. Governments and international organizations are also implementing stricter regulations, prompting companies to adopt more conscious practices.

The "Cradle to Cradle" framework, which emphasizes the creation of systems where materials are perpetually reused, has provided a robust lens through which the results of this study can be interpreted. Adopting this framework reveals that companies are not merely reducing waste; rather, they are designing processes that enable the continual regeneration of materials. In the context of the fashion industry, "Cradle to Cradle" supports the transition from a linear model to a regenerative model where resources are used in cycles, contributing to both environmental and business sustainability. The technology and practices explored in this study, particularly through the use of Materia MX, align with "Cradle to Cradle" principles by fostering resource efficiency, waste minimization, and material recycling. Consequently, enterprises that adopt these circular practices not only mitigate their environmental impact but also establish systems that are inherently regenerative, ensuring long-term sustainability. Nevertheless, significant barriers exist that impede the implementation of "Cradle to Cradle" policies on a global scale, particularly within sectors such as fashion. These barriers include high initial costs, a lack of globally consistent regulations, and resistance to change within well-established industries. In addition, the global nature of supply chains poses challenges in ensuring the uniform implementation of circular practices across different countries with varying levels of infrastructure and regulatory oversight. Technology, such as the use of AI and blockchain, can help mitigate these challenges by enabling better traceability, ensuring compliance, and enhancing transparency, particularly in regions with less stringent regulations. It is also imperative that policy frameworks for circularity are designed with the unique needs of the fast fashion sector, as opposed to the luxury sector, in mind.

The analysis of the strategies that the companies considered in this study are pursuing in terms of circularity allows us to obtain information on the future of fashion and the innovative approaches that are shaping a more sustainable and circular industry.

The comparison between the positions that emerged from the literature in terms of barriers and drivers for circularity and the strategies of the companies considered brought out several key factors, such as the growing awareness and demand for conscious fashion by consumers, regulatory pressure from governments and the growing recognition of resource scarcity and environmental degradation caused by linear production models. Additionally, companies are recognizing the long-term benefits of adopting circular strategies, including resource efficiency and potential cost savings through recycling and reuse practices. However, the fashion industry faces significant obstacles to fully embrace the circular economy. These include a lack of training on the subject, uncertainty about circular processes and, above all, the need for high initial investments.

In addition, the case studies examined made it possible to identify an element that has proven to make a difference in this transformation process: technology. These three companies have recently decided to enter into a partnership with an innovative company, known as Queen of Raw, which is working to make surplus waste and resources available and accessible to other organizations' secondary raw materials. This project addresses one of the biggest problems that the fashion industry is experiencing, namely the overproduction of waste.

This research aims to offer new insights into the critical role of technology and innovation in enabling the transition to circularity in the fashion industry, making it a source of

competitive advantage when leveraged correctly. On the contrary, the analysis showed that the lack or refusal to introduce the technology not only represents a disadvantage in the face of competition but could jeopardize the company's business as a whole. Despite these advances, it must be said that technological solutions alone are insufficient. To achieve true circularity, a change in consumer behavior, corporate, and appropriate regulatory frameworks are also needed. Collaboration between industry stakeholders, policymakers, and consumers is key to overcoming challenges and promoting a circular economy that benefits both environmental and business sustainability.

The findings of this study carry significant policy implications for the fashion industry, as well as for policymakers and regulatory bodies. It is recommended that policymakers consider the promotion or prescription of technologies that support circular practices, such as Materia MX, which facilitates the simplification of waste management and the enhancement of resource efficiency. These policies would be in alignment with the principles of "Cradle to Cradle", encouraging industries to innovate and establish systems of perpetual regeneration of resources.

In addition, governments could introduce incentives for companies adopting these technologies, offering tax breaks or funding for sustainability initiatives. To encourage wider adoption of circular business models, governments could push for the adoption of global standards for circularity, particularly in sectors with significant environmental impact, such as fashion. The implementation of standards aligned with "Cradle to Cradle" principles has the potential to ensure that companies not only reduce waste but also design products and processes that contribute to a restorative and regenerative economy.

Furthermore, the implementation of educational awareness campaigns that emphasize the environmental benefits of circular fashion is crucial in helping consumers understand how they can participate in reducing waste. Initiatives of this kind would help consumers understand the value of products designed for reuse and their role as integral components of a "Cradle to Cradle" inspired circular system.

In addition, educational awareness campaigns that emphasize the environmental benefits of circular fashion are also crucial to making consumers understand how they can participate in reducing waste. Initiatives of this nature would assist consumers in comprehending the value of products designed for reuse and their role as integral components of a "Cradle to Cradle"-inspired circular system. Policies aimed at enhancing transparency, such as the implementation of mandatory labeling for sustainable products, could further stimulate consumer demand for circular products. The findings of this study also have significant implications for future research, as this work highlights the potential of technology to accelerate the adoption of circular economy principles. The potential exists for future studies to investigate how artificial intelligence, blockchain, and the IoT, as well as tools such as Materia MX, can support other industries in implementing circular practices. Furthermore, a comparative study between sectors could provide valuable information on the scalability of these technologies. A further area of potential research could be the collaboration between sectors, for example, in the form of partnerships between fashion companies, technology companies, and recycling industries, which could result in the creation of innovative circular solutions. Alternatively, the focus could be on consumer behavior and, in particular, on their perceptions regarding circular fashion and how technological innovations influence purchasing behavior.

The proposed work has limitations. Firstly, the sample considered in the analysis is limited, also due to the fact that the interest in circular economy practices is quite recent. Secondly, this work only takes into account the introduction of specific software, Materia MX by the Queen of Raw company, and its impact on fashion companies. Finally, a further limitation is represented by the scarcity of relevant data disclosed by companies on the

use of the software in question. As a result, future research could broaden the sample of companies and also investigate the results over time, performing longitudinal studies with a focus on the same companies. To address the inherent limitations of the data, it is recommended that future longitudinal studies explicitly consider this issue. One potential approach would be to track measurable outcomes by focusing on long-term sustainability metrics, such as resource savings, reduction in waste, and cost-effectiveness over time. In addition, it would be beneficial to examine how emerging technologies influence the quantifiable impacts of circular practices on companies' environmental footprints and profitability. Such studies would help to bridge the gap between technology adoption and the tangible outcomes of sustainability, offering more comprehensive data on the effectiveness of these tools. To conclude, different forms of technology, operating along different stages of the value chain, both alone and combined, could be considered in order to achieve the best possible outcome for companies and the environment.

In conclusion, this study offers both theoretical contributions to the literature on the circular economy, strategic management, and the fashion industry and practical implications for policy and future research. The results emphasize the importance of technology in overcoming barriers to circularity and accelerating the transition to a more sustainable fashion industry.

**Author Contributions:** Conceptualization, P.G., E.P., R.H. and R.R.; Methodology, P.G. and R.H.; Validation, P.G., E.P., R.H., V.V. and R.R.; Investigation, P.G. and E.P.; Resources, P.G.; Data curation, R.R.; Writing—original draft, E.P., V.V. and R.R.; Writing—review & editing, P.G., E.P., R.H. and V.V.; Visualization, V.V.; Supervision, R.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is part of the—project NODES which has received funding from the MUR—M4C2 1.5 of PNRR funded by the European Union NextGenerationEU (Grant agreement no. ECS00000036) and CUP J83B22000050001.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are available in the web site of the companies: SHEIN: https://www.sheingroup.com/. Ralph Lauren: https://corporate.ralphlauren.com. Cotopaxi: https://www.cotopaxi.com.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Gazzola, P.; Pavione, E.; Pezzetti, R.; Grechi, D. Trends in the fashion industry. The perception of sustainability and circular economy: A gender/generation quantitative approach. *Sustainability* **2020**, *12*, 2809. [CrossRef]
2. Leal Filho, W.; Perry, P.; Heim, H.; Dinis, M.A.P.; Moda, H.; Ebhuoma, E.; Paço, A. An overview of the contribution of the textiles sector to climate change. *Front. Environ. Sci.* **2022**, *10*, 973102. [CrossRef]
3. Ellen Macarthur Foundation. It's Time for a Circular Economy. Available online: https://www.ellenmacarthurfoundation.org// (accessed on 27 December 2024).
4. Webster, K. A Circular Economy Is About the Economy. *Circ. Econ. Sustain.* **2021**, *1*, 115–126. [CrossRef]
5. Hugo, A.; de Nadae, J.; da Silva Lima, R. Can fashion be circular? A literature review on circular economy barriers, drivers, and practices in the fashion industry's productive chain. *Sustainability* **2021**, *13*, 12246. [CrossRef]
6. Tura, N.; Hanski, J.; Ahola, T.; Ståhle, M.; Piiparinen, S.; Valkokari, P. Unlocking circular business: A framework of barriers and drivers. *J. Clean. Prod.* **2019**, *212*, 90–98.
7. Monyaki, N.C.; Cilliers, R. Defining drivers and barriers of sustainable fashion manufacturing: Perceptions in the global south. *Sustainability* **2023**, *15*, 10715. [CrossRef]
8. Scipioni, S.; Russ, M.; Niccolini, F. From barriers to enablers: The role of organizational learning in transitioning SMEs into the circular economy. *Sustainability* **2021**, *13*, 1021. [CrossRef]

9. Akram, W.; Mia, R.; Ullah, S.; Assiri, M.A.; Fang, J. Simultaneous synthesis and application of $TiO_2$ nanoparticles using mulberry leaves for functionalization of organic cotton fabric. *J. Clean. Prod.* **2024**, *440*, 140939. [CrossRef]
10. Alves, L.; Ferreira Cruz, E.; Lopes, S.I.; Faria, P.M.; Rosado da Cruz, A.M. Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: A review. *Waste Manag. Res.* **2022**, *40*, 3–23. [CrossRef]
11. Geissdoerfer, M.; Savaget, P.; Bocken, N.; Hultink, E.J. Prototyping, experimentation, and piloting in the business model context. *Ind. Mark. Manag.* **2022**, *102*, 564–575.
12. De Keyser, E.; Mathijs, E. A typology of sustainable circular business models with applications in the bioeconomy. *Front. Sustain. Food Syst.* **2023**, *6*, 1028877. [CrossRef]
13. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232.
14. Casciani, D.; D'Itria, E. Fostering Directions for Digital Technology Adoption in Sustainable and Circular Fashion: Toward the Circular Fashion-Tech Lab. *Systems* **2024**, *12*, 190. [CrossRef]
15. Chen, Y. How blockchain adoption affects supply chain sustainability in the fashion industry: A systematic review and case studies. *Int. Trans. Oper. Res.* **2024**, *31*, 3592–3620.
16. Al-kfairy, M. Strategic Integration of Generative AI in Organizational Settings: Applications, Challenges and Adoption Requirements. In *IEEE Engineering Management Review*; IEEE: New York, NY, USA, 2025.
17. McDonough, W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: Berkeley, CA, USA, 2002.
18. United Nations. Environmental Programme. Annual Report: "Putting the Environment at the Heart of People's Lives". 2018. Available online: https://digitallibrary.un.org/record/4051787/files/1409542-EN.pdf (accessed on 2 January 2025).
19. Geneva Environment Network. Environmental Sustainability in the Fashion Industry. 2024. Available online: www.genevaenvironmentnetwork.org/resources/updates/sustainable-fashion/ (accessed on 2 January 2025).
20. Bailey, K.; Basu, A.; Sharma, S. The Environmental Impacts of Fast Fashion on Water Quality: A Systematic Review. *Water* **2022**, *14*, 1073. [CrossRef]
21. Bick, R.; Halsey, E.; Ekenga, C.C. The global environmental injustice of fast fashion. *Environ. Health* **2018**, *17*, 92. [CrossRef] [PubMed]
22. Wójcik-Karpacz, A.; Karpacz, J.; Brzeziński, P.; Pietruszka-Ortyl, A.; Ziębicki, B. Barriers and drivers for changes in circular business models in a textile recycling sector: Results of qualitative empirical research. *Energies* **2023**, *16*, 490. [CrossRef]
23. Abdelmeguid, A.; Afy-Shararah, M.; Salonitis, K. Investigating the challenges of applying the principles of the circular economy in the fashion industry: A systematic review. *Sustain. Prod. Consum.* **2022**, *32*, 505–518.
24. Alivojvodic, V.; Kokalj, F. Drivers and Barriers for the Adoption of Circular Economy Principles towards Efficient Resource Utilisation. *Sustainability* **2024**, *16*, 1317. [CrossRef]
25. Hina, M.; Chauhan, C.; Kaur, P.; Kraus, S.; Dhir, A. Drivers and barriers of circular economy business models: Where we are now, and where we are heading. *J. Clean. Prod.* **2022**, *333*, 130049.
26. Silva, E.R.; Lohmer, J.; Rohla, M.; Angelis, J. Unleashing the circular economy in the electric vehicle battery supply chain: A case study on data sharing and blockchain potential. *Resour. Conserv. Recycl.* **2023**, *193*, 106969.
27. Han, Y.; Shevchenko, T.; Yannou, B.; Ranjbari, M.; Shams Esfandabadi, Z.; Saidani, M.; Li, G. Exploring how digital technologies enable a circular economy of products. *Sustainability* **2023**, *15*, 2067. [CrossRef]
28. Ostermann, C.M.; Nascimento, L.D.S.; Zen, A.C. Business model innovation for circular economy in fashion industry: A startups' perspective. *Front. Sustain.* **2021**, *2*, 766614.
29. Farrukh, A.; Sajjad, A. Drivers for and barriers to circular economy transition in the textile industry: A developing economy perspective. *Sustain. Dev.* **2024**, *32*, 7309–7329.
30. Ekins, P.; Domenech, T.; Drummond, P. Policies for a resource efficient economy in Europe: Findings from the POLFREE project. *Ecol. Econ.* **2019**, *155*, 1–6.
31. Hong, Y.; Kang, Z.; Fan, J. Revolutionizing textile: Advanced techniques for superior thermal conductivity. *Compos. Part A Appl. Sci. Manuf.* **2024**, *186*, 108380. [CrossRef]
32. Ghoreishi, M.; Happonen, A.; Pynnönen, M. Exploring Industry 4.0 Technologies to Enhance Circularity in Textile Industry: Role of Internet of Things. In Proceedings of the Twenty-first International Working Seminar on Production Economics, Innsbruck, Austria, 24–28 February 2020; pp. 1–16. [CrossRef]
33. Munir, N.; Tariq, R.; Abideen, Z.; Hasnain, M.; Hussain, M.I.; Haq, R. Efficient detoxification of textile wastewater by applying Chenopodium album nanoparticles and its application in simulated metal-bearing effluents removal. *Environ. Sci. Pollut. Res.* **2023**, *30*, 60890–60906. [CrossRef]
34. Zhao, P.; Song, Y.; Xie, P.; Zhang, F.; Xie, T.; Liu, G.; Zhao, J.; Han, S.-T.; Zhou, Y. All-Organic Smart Textile Sensor for Deep-Learning-Assisted Multimodal Sensing. *Adv. Funct. Mater.* **2023**, *33*, 2301816. [CrossRef]

35. Yuan, H.; Liu, R.; Cheng, S.; Li, W.; Ma, M.; Huang, K.; Li, J.; Cheng, Y.; Wan, K.; Liu, Z. Scalable fabrication of dual-function fabric for zero-energy thermal environmental management through multiband, synergistic, and asymmetric optical modulations. *Adv. Mater.* **2023**, *35*, 2209897. [CrossRef]
36. Porter, M.E. Technology and competitive advantage. *J. Bus. Strategy* **1985**, *5*, 60–78.
37. Vlados, C.; Chatzinikolaou, D.; Iqbal, B.A. New Globalization and Multipolarity. *J. Econ. Integr.* **2022**, *37*, 458–483.
38. Mintzberg, H. Rethinking strategic planning part I: Pitfalls and fallacies. *Long Range Plan.* **1994**, *27*, 12–21.
39. Peters, T.J.; Waterman, R.H., Jr. *Search of Excellence*; Harper and Row: New York, NY, USA, 1982.
40. Rose, K.; Eldridge, S.; Chapin, L. The internet of things: An overview. *Internet Soc. (ISOC)* **2015**, *80*, 1–53.
41. IBM. What is Blockchain? Available online: www.ibm.com/topics/blockchain (accessed on 20 December 2024).
42. Gazzola, P.; Pavione, E.; Barge, A.; Fassio, F. Using the transparency of supply chain powered by blockchain to improve sustainability relationships with stakeholders in the food sector: The case study of Lavazza. *Sustainability* **2023**, *15*, 7884. [CrossRef]
43. IBM. What is Artificial Intelligence (AI)? Available online: www.ibm.com/topics/artificial-intelligence (accessed on 20 December 2024).
44. IBM. What is Machine Learning (ML)? Available online: www.ibm.com/topics/machine-learning (accessed on 20 December 2024).
45. IBM. What is Big Data Analytics? Available online: www.ibm.com/topics/big-data-analytics (accessed on 20 December 2024).
46. Google Cloud. What is Big Data? Available online: https://cloud.google.com/learn/what-is-big-data?hl=en (accessed on 20 December 2024).
47. Tsai, W.; Bai, X.; Huang, Y. Software-as-a-service (SaaS): Perspectives and challenges. *Sci. China Inf. Sci.* **2014**, *57*, 1–15.
48. Baumgart, M.; McDonough, W. Cradle to Cradle (Patterns of the Planet) (Kindle Edi). 2009. Available online: https://www.amazon.com/Cradle-Patterns-Planet-Lifeebook/dp/B0031RDV9G (accessed on 2 January 2025).
49. Eisenhardt, K.M. Building theories from case study research. *Acad. Manag. Rev.* **1989**, *14*, 532–550.
50. Yin, R.K. *Case Study Research: Design and Methods*, 5th ed.; SAGE Publication: London, UK, 2013.
51. SHEIN. SHEIN Sets Ambition to Become Global Leader in Rescuing Industrys Excess Inventory Through Circular Economy Technology in Partnership with Queen of Raw. 2023. Available online: www.sheingroup.com/corporate-news/press-releases/shein-sets-ambition-to-become-global-leader-in-rescuing-industrys-excess-inventory-through-circular-economy-technology-in-partnership-with-queen-of-raw/ (accessed on 20 December 2024).
52. Time. Shein Is the World9s Most Popular Fashion Brand—At a Huge Cost to Us All. 2023. Available online: https://time.com/6247732/shein-climate-change-labor-fashion/ (accessed on 20 December 2024).
53. Jumpstart Magazine. Shein9s Road to IPO: What Are the Controversies of Shein? 2024. Available online: www.jumpstartmag.com/sheins-road-to-ipo-what-are-the-controversies-of-shein/ (accessed on 20 December 2024).
54. SHEIN Group. Sharing Our evoluSHEIN Roadmap to Guide the Future of Sustainability & Social Impact at SHEIN. 2023. Available online: https://www.sheingroup.com/corporate-news/company-updates/sharing-our-evolushein-roadmap-to-guide-the-future-of-sustainability-social-impact-at-shein/ (accessed on 19 December 2024).
55. Ralph Lauren Corporation. Our Company. Available online: https://corporate.ralphlauren.com/on/demandware.store/Sites-RalphLauren_Corporate-Site/default/Home-Show (accessed on 21 December 2024).
56. Ralph Lauren. Ralph Lauren Vintage. Available online: www.ralphlauren.com/vintageandantiques (accessed on 21 December 2024).
57. Cotopaxi. Available online: https://www.cotopaxi.com/ (accessed on 20 December 2024).
58. B Lab Global. About B Corp Certification, Measuring a Company9s Entire Social and Environmental Impact. Available online: www.bcorporation.net/en-us/certification/ (accessed on 20 December 2024).
59. Queen of Raw. Ralph Lauren9s CEO Celebrates Achievements Through Queen of Raw's Materia MX. 2022. Available online: www.queenofraw.com/case-studies/ralph-laurens-ceo-celebrates-achievements-through-queen-of-raws-materiamx/index.html (accessed on 19 December 2024).
60. Between Conscious. Queen of Raw: Sustainability as a Solution. Available online: https://betweenconscious.com/en/blog/queen-of-raw-sustainability-as-a-solution (accessed on 20 December 2024).
61. Matende, S.; Ogao, P. Enterprise resource planning (ERP) system implementation: A case for user participation. *Procedia Technol.* **2013**, *9*, 518–526.
62. Trieu, V.H. Getting value from Business Intelligence systems: A review and research agenda. *Decis. Support Syst.* **2017**, *93*, 111–124.

63. Forbes. Shein Partners with Queen of Raw to Rescue Fashion Industries DeadStock. 2023. Available online: https://www.forbes.com/sites/sharonedelson/2023/05/16/shein-partners-with-queen-of-raw-to-rescue-fashion-industrys-deadstock/ (accessed on 20 December 2024).
64. Glory Media. Queen of Raw CEO Stephanie Benedetto Is Combatting the World9s Water Crisis One Textile at a Time. Available online: https://www.glory.media/queen-of-raw-ceo-stephanie-benedetto-is-combatting-the-worlds-water-crisis-one-textile-at-a-time/ (accessed on 21 December 2024).