

Article

# Fostering Fashion Ecosystems: A Quadruple Helix-Based Model for European Sustainable Innovation

Erminia D'Itria \*  and Chiara Colombi

Design Department, Politecnico di Milano, 20158 Milan, Italy; chiara.colombi@polimi.it

\* Correspondence: erminia.ditria@polimi.it

**Abstract:** Industrial sectors' innovative and sustainable development relies not only on solid government, society, academia, and industry but also on how they interact to set and implement strategic goals. In the fashion industry context, the new sociocultural scenario is increasingly driven by pressures from stakeholders to limit the impacts of industrial practices and to move toward new open ecosystems to create and maintain sustainable innovation. This article explores how such innovation can be enabled by design-driven actions in the context of the quadruple helix. Such a model aims to revitalize the areas of technological innovation and gradually advance the construction of the infrastructure needed for sustainable fashion growth, combining and integrating different knowledge. An initial literature review, complemented by case studies analysis, identifies the European fashion industry dynamics of innovation and the roles of industry, government, university, and society. In particular, the government is transforming from a mere controller to a facilitator of innovation synergies. Society relies on citizens revising their consumption habits by shifting toward a performative economy. Industry understands the need for collaboration and adopts new closed-loop supply chains to create and maintain its sustainable development. Universities enable new open system flows to make innovations concerning knowledge, technologies, and systems thrive, from technology transfer to knowledge co-creation. Based on the analysis, we propose a conceptual framework to understand the micro- and macro-dynamics of open innovation with a quadruple helix model to implement sustainability practices in the fashion sector through design-driven actions—reuse, repair, recycle, and refashion—that aim to eliminate the concept of waste to support local ecosystems toward establishing a closed-loop chain.



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**Keywords:** fashion design for circularity; eco-systemic innovation; quadruple helix model; industry transformation

## 1. Introduction

Today, the European Union is implementing a swift and broad transition to ecologically sustainable lifestyles and industries to preserve the planet's viability and take advantage of digital opportunities [1–3]. This is the twin transition: a green and digital transition to achieve sustainable, just, and competitive success [4]. The green transition strives to promote sustainability, stop climate change, and protect the environment [5]. In parallel, societies and economies are changing due to the increasing relevance of digital technologies [6]. The EU wants to use digital technology to empower citizens and businesses while fostering sustainability and prosperity [7]. Although green and digital technologies will be crucial to the “green transition”, how effectively they are implemented will be influenced by a number of economic, social, and political issues [8,9]. The different surrounding variables that influence the twin transitions must be properly taken into account. The financial costs of the two transitions, the business opportunities they provide, the employment transfers between rising and declining industries, and the funding of the required investments are all economic variables. Acceptance, justice, and behavioral modification are social factors. Regulations, standards, and geopolitical considerations are all political elements. The green

and digital technologies necessary for the twin transitions can only be scaled if these contextual factors are managed appropriately [10]. This new EU strategy aims to deliver growth through strategic actions involving the following actors: (1) academia, which will invest more effectively in education, research, and innovation; (2) industry, which will move toward a circular economy; (3) society, which will place a strong emphasis on involving the general public in co-creation processes; and (4) government, which will involve the political and legal capital. Based on these four mutually reinforcing priorities, the European Union aspires to overcome the crisis and establish the prerequisites for a more sustainable future. This strategy intends to support Member States and their areas in achieving higher levels of employment, productivity, and social cohesion in a way that is competitive worldwide and, as a result, environmentally, financially, and socially sustainable [3]. In the presented context, the authors explore the evolution of a specific industry sector: fashion. Fashion is understood as a single dimension that includes fashion and textiles by combining the various aspects related to natural sciences, human sciences, social sciences, and the arts. Indeed, these two dimensions are increasingly intertwined in today's fast-changing and increasingly complex academic and industrial environment. According to the European Commission [11], this is a crucial sector because, after housing, food, and mobility, it has the fourth biggest effect on the health of the planet and climate change. Additionally, it ranks third in terms of consumption of soil and water and fifth in terms of emissions of greenhouse gases and the usage of key raw materials [11]. The authors propose conceptual frameworks to codify innovation, based on the Quadruple Helix model of innovation (academia, industry, government, and civil society), to imagine fashion ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real-life communities and settings for implementing circular practices. Such a model could draw a future path for a circular fashion system in which innovative organizational and productive processes could nurture the industry's transition to a closed-loop paradigm. Section 2 describes the systematic review of (1) the literature on quadruple helix models and (2) the Living Lab as real-life testing and experimentation environments of such models. The literature looks at them from a triple perspective: (1) as a subject of research for academics, (2) as a methodology to ensure valid and reliable results, and (3) as a tool for practitioners to handle contemporary world challenges [12]. Such perspectives support the authors in developing their framework and discussing the propositions of this research. Section 3 presents methods, materials, and the mapping experience of European fashion companies' innovation initiatives. This phase of the study was conducted iteratively to model the data that guided the creation of the research model. According to the scope of the study, the decision to focus on the European region specifically is related to different factors: (1) The European Commission's new directives under the Green Deal program. As discussed, the proposed package of policy initiatives aims to promote a green transition by involving the quadruple helix actors and stimulating innovation as a catalyst for sustainable growth. The new EU directives focus on developing an innovation-driven transition infrastructure needed to drive transformative change for accelerating and navigating the necessary transitions, imagining and implementing effective solutions, and engaging citizens in social innovation [3]. (2) The fashion industry's role in the European economy, as a leader in world markets. The EU produces an annual turnover of 169 billion with 160,000 companies and employs 1 million people, earning 67 billion in extra-EU exports every year [13]. (3) The collective knowledge and skills of the research team, of which the authors are members, generated from academic research, teaching, networking, and further projects in fashion design and circularity. Section 4 reports the results and analyzes current ecosystems that engage the quadruple helix actors in innovation initiatives fostering interaction and collaboration. The model describes the dynamics of open innovation within a quadruple helix model to implement sustainability practices, in the fashion sector, through design-driven actions. Sections 4.1–4.4 discuss the four identified design-driven actions that strategically engage the four actors in eliminating the notion of waste to support local ecosystems toward a closed loop, namely: (1) Reuse—welcoming designers, private indi-

viduals, students, fashion artisans offering a purchasing service for fabrics and accessories from warehouse stocks, samples, second choices and end of production also offer training courses on fabrics and accessories in a sustainable perspective; (2) Repair—exploring and collaborating with local communities of businesses and citizens to act on their consumption and reduce the waste of textile products; (3) Refashion—creating new products, possibly redesigning the function of use, resulting in a greater value than the original product; and (4) Recycle—using waste as materials that can be reused in other production cycles. Section 5 concludes the paper by explaining how the presented model creates research opportunities to understand how different quadruple helix actors can collaborate to design and establish new strategies to foster collective innovation and development, through knowledge sharing, experimentation, and validation of new circular products, services, systems, and solutions. It also reports the limits and future perspectives of the research.

## 2. Literature Review

A preliminary literature review was conducted to develop the study's theoretical foundation. As a result, it was possible to formulate the propositions of the research model. In this initial phase, we refer to selected databases: Scopus, Science Direct, and Google Scholar to provide thorough coverage of the subject. Specifically, we included scientific books, papers, conference proceedings, and scientific articles. This initial consult supports the notion that the whole society is involved in innovation resulting from the four helices' mutual co-creation and is connected to them by networks, partnerships, and symbiotic interactions [14]. Since the study aimed to examine the current state of the art, we focused on the time frame from 2012 to 2022. The topics studied involved interdisciplinary fields in which design, management, architecture, and engineering predominated. As a result of this first phase, seven keywords were identified and researched according to the following query: Quadruple AND Helix AND Model AND Sustainable AND Innovation AND Fashion AND Textiles. From the selected query, 129 documents were found. The research applied to titles, abstracts, and keywords for Scopus, Science Direct, and "any type" for Google Scholar. The filtering procedure required the following steps. The titles and abstracts were first reviewed to avoid publications unrelated to the topic of bringing together the actors of the quadruple helix to promote innovation ecosystems. The papers were checked for excluding duplicates, and the remaining 30 publications were fully examined. A comprehensive reading was conducted to conclude the analysis. This additional phase was based on the following document inclusion criteria: (1) date of publication—only articles published within the last ten years; (2) language of publication—only articles in English; (3) study design—both qualitative and quantitative studies; and (4) outcomes—articles with literature reviews, frameworks, and guidelines that could support the investigation of methods for fostering innovation in the quadruple helix context. The first full reading showed that almost all articles were related to quadruple helix models for innovation ecosystems. To begin to codify the models presented and create the framework for the study, we included only articles that presented extensive discussions of the study's objectives or illustrated their practical implications, particularly the Living Lab movement. This movement consists of environments in which quadruple helix stakeholders collaborate on the creation of new solutions using iterative feedback processes during an innovation life-cycle approach to create sustainable impact [15,16]. After that, papers that supported models that had been previously identified were chosen for a second round of reading. The sample was down to 18 publications after this last selection. The literature review process presented here is reported in Table 1 while the final publications list is reported in Table 2.

This systematic review supported the basic structure of the study model proposed by the authors. It enabled the investigation of iterative processes of information sharing and collaboration among many actors to produce innovation capable of driving the fashion industry toward circular paths. Such routes redefine the whole concept of waste to deliberately change the beginning and end of the supply chain toward a circular model from a life-cycle perspective. We referred to the quadruple helix actors' dual roles as both barriers

and catalysts for a circular fashion ecology. On the one hand, they work with distinct horizon management, and there needs to be a better understanding of the sustainability of such cooperation from the perspective of the stakeholders who will be involved in such projects. On the other hand, several studies used the quadruple helix model as a circularity enabler to describe the drivers of knowledge production and innovation required for environmental preservation, green technology generation, problem-solving, and transitioning society into a circular economy [17,18]. The scientific literature has revealed how the construction of models in which bottom-up efforts backed by top-down programs—such as the one presented in this article—are thought to provide the best results [19]. These models illustrate considerations of the quadruple helix model as a circular design principle in which technological and social innovations result from cooperation and seeking synergies among the four stakeholder groups, integrating and overlapping knowledge and technologies. These iterations result in aggregate output invested in the production of multiple products and services, innovation, and technology designed for circularity.

**Table 1.** Literature review workflow.

Document included (typology)	Scientific Articles, Conference Proceedings, Book and Chapters Reports
Time Horizon	2012–2022
Keywords	Quadruple AND Helix AND Model AND Sustainable AND Innovation AND Fashion AND Textiles
Search Applied to Titles, Abstract, and Keywords	Scopus → 16 references Science Direct → 13 references Google Scholar → 100 references
Screening of Titles and Abstract	30 references, excluding publications unrelated to the study
Full-Text Analysis and Final Selection	18 references, selecting only publications that support some of the practices identified further

**Table 2.** Final documents selection.

Title	Type	Year	Quadruple Helix Model	Living Lab Movement	Strategies for Sustainable Innovation
A Growth Model for the Quadruple Helix	Journal Article	2012	x		
A systematic review of Living Lab literature	Review Article	2019			x
Co-creation for Responsible Research and Innovation	Book	2022	x	x	
Experimenting with Design Methods and Tools Co-shaping the Future in Quadruple Helix Innovation Systems: Uncovering Public Preferences toward Participatory Research and Innovation	Article	2019	x		x
Evolution of strategic interactions from the triple to quad helix innovation models for sustainable development in the era of globalization	Review Article	2016	x		x
Inclusive Entrepreneurship, Creativity and Innovation in a Quadruple Helix Perspective: Analysis of practical cases	Report	2015	x		
Living Labs: A systematic literature review	Article	2015		x	
Living labs to develop reuse and repair workshops in territories	Paper	2019		x	

Table 2. Cont.

Title	Type	Year	Quadruple Helix Model	Living Lab Movement	Strategies for Sustainable Innovation
Micro- and Macro-Dynamics of Open Innovation with a Quadruple Helix Model	Editorial	2019	x		
Quadruple Helix Mapping Collaboration for Fashion Small Medium Enterprise Development in Bandung	Article	2015	x		
Quadruple Helix Models for Sustainable Regional Innovation: Engaging and Facilitating Civil Society Participation	Article	2020	x		
Social Innovation Playbook	Report	2020	x		x
Stages of the Portuguese textile, clothing, and fashion sector—a case of the triple helix model	Conference Proceedings	2021	x		
The ecosystem as helix: an exploratory theory-building study of regional competitive entrepreneurial ecosystems as Quadruple/Quintuple Helix Innovation Models	Article	2017	x		
The Quadruple/Quintuple Innovation Helixes and Smart Specialisation Strategies for Sustainable and Inclusive Growth in Europe and Beyond	Article	2014	x		
Tools and Technologies for Sustainable Territorial Development in the Context of a Quadruple Innovation Helix	Article	2022	x		x
Triple Helix or Quadruple Helix: Which Model of Innovation to Choose for Empirical Studies?	Article	2022	x		
Unveiling the Evolution of Innovation Ecosystems: An Analysis of Triple, Quadruple, and Quintuple Helix Model Innovation Systems in European Case Studies	Review Article	2021	x		

### 3. Materials and Methods

Methodologically, a desk research phase was followed by a case study methodology to restrict a broad scope of research into easily searchable areas. According to Yin [20], this method is particularly suitable for analyzing existing knowledge on a specific topic because it deals with research complexities by transforming the specific case into an operational component that can be explored in its original context, thus incorporating multiple elements and characteristics. Furthermore, Johansson [21] illustrated how the case study approach is appropriate for bridging the gap between quantitative and qualitative methodologies by an inductive theory-building generalization mode. Because the use of quadruple helix models is currently a topic of limited research [22–24], the case study technique provides concrete information that, while not generalizable, enables the establishment of understanding through the selected case studies [25]. The processed data are collected from the knowledge repository of the Fashion in Process Research Lab at Politecnico di Milano. The data stem specifically from the authors' participation in three international field studies involving a consortium of European academic and research institutions [26–28] and the results of one of the authors' doctoral studies [29]. The initial phase of the research dealt with mapping how European fashion companies engage in circular intersectoral initiatives, allowing strategic actions to be developed to promote an expanded awareness of what virgin material is and encourage a reassessment of the concept of new. This paradigmatic change is fostered by the multi-disciplinary networks nurturing interaction and collaboration from the different perspectives of all the quadruple helix actors. This first phase of mapping identified 23 initiatives, of which 20 are located in 9 nations on



the European continent, 1 intercontinental that is being developed between Italy and the Hymalaini territories, and 1 located in Brazil (Figure 1).

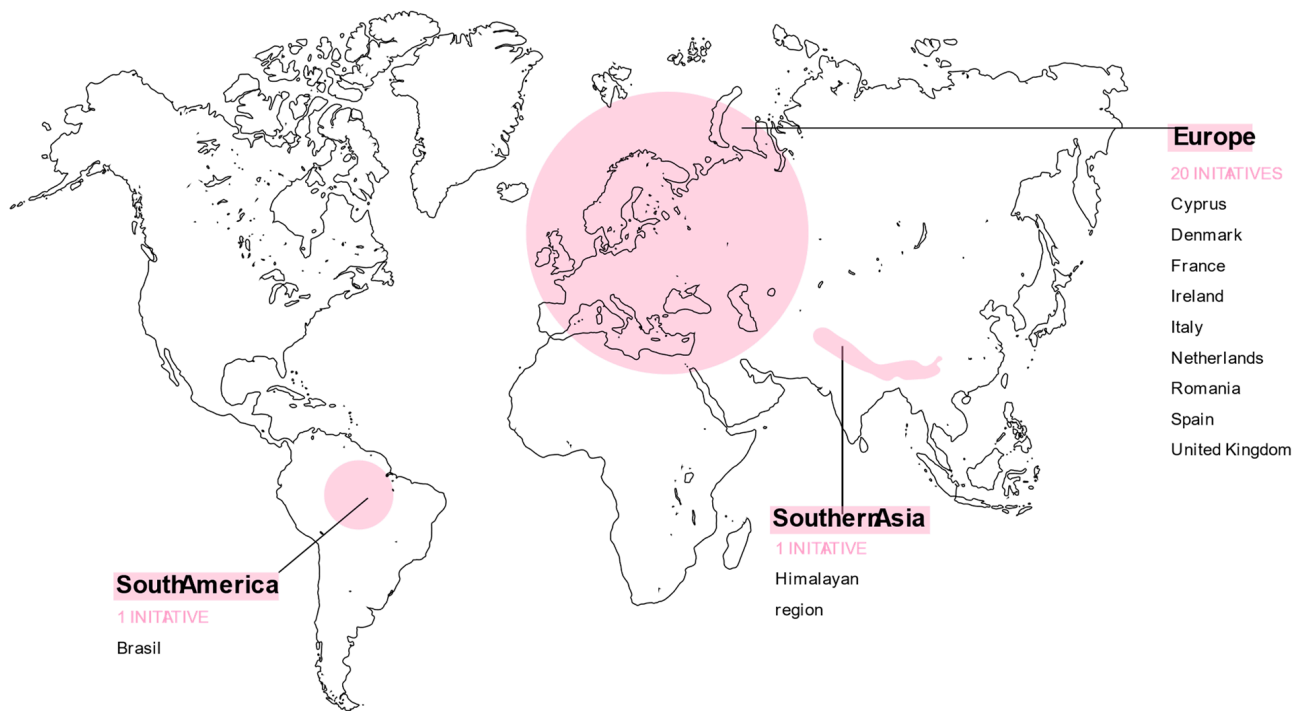


Figure 1. Companies map.

These initiatives were recognized for developing, from various perspectives, a framework for promoting the innovation system through interdisciplinary networks structured to encourage interaction and collaboration, as well as supporting these networks through the development and maintenance of their technological infrastructure, as well as the provision of relevant knowledge and services (Table 3).

Table 3. List of the mapped initiatives.

Country	Sector	Name	Description
Brasil	Organizational innovation	Sustainable Fashion Lab	The Sustainable Fashion Lab is a national, multi-sectoral platform for collaboration and innovation that consists of approximately 40 leaders and aims to address and transform the main challenges of Brazil’s fashion industry.
Cyprus	Business model transformation	Anakyklos	Anakyklos is a public clothing bank for collecting unwanted clothing. These are sold through their charity shops or textile recycling.
Denmark	Business model transformation	GANNI	Ganni is a contemporary ready-to-wear fashion brand for women.
France	Organizational innovation	Veja	Veja is an innovative sneaker brand based in Paris.
France	Organizational innovation	Tissu Market (Valentino Sleeping Stock)	Promotes the creative reuse of the Italian fashion house’s stock and its “dormant” fabrics by offering them to different communities.

Table 3. Cont.

Country	Sector	Name	Description
France	Organizational innovation	LVMH (DARE)	DARE (disrupt, act, risk to be an entrepreneur), is LVMH's program that serves as an incubator for new ideas, and with the support of LVMH's Environmental Development division. The project analyzed is the first online resale platform that offers a second chance to high-quality fabrics and leathers that can no longer be used by the group's fashion houses.
Ireland	Business model transformation	Nu Wardrobe	Nu Wardrobe is a community and online clothes-sharing platform.
Italy	Organizational innovation	Apulia Regenerative Cotton Project	The Apulia Regenerative Cotton Project will focus on the development of agroforestry-based cotton production.
Italy	Organizational innovation	ASTRI	Italian Textile and Recycling Association (A.S.T.R.I.) was born to increase the value of what Prato has been doing for decades, that is to produce regenerated textiles.
Italy	Organizational innovation	Comistra	From the ancient textile district of Prato, Italy, Comistra produces mechanical high-quality wool by recovering waste from the Italian textile industry.
Italy	Organizational innovation	Lottozero	Lottozero is a center for textile design and art, based in Prato, Italy, with an open lab for textile production, experimentation, and research.
Italy	Process innovation	Simon Cracker	The brand Simon Cracker was born in 2010 from the idea of Simone Botte, art director, stylist, and fabrics and printings researcher, as an upcycling clothing line, giving a second chance to "forgotten" garments, deadstock fabrics, and everything discarded by other people.
Italy	Process innovation	Tessiture Bevilacqua E Tiziano Guardini	This project is between a sustainable designer, nine Venetian companies, and an ancient Venetian weaving mill founded in 1499. The goal: to stimulate the revitalization of high Venetian craftsmanship and the Venetian fashion system.
Italy	Process innovation	Vitelli	Vitelli is a regenerative fabric design and clothing maker. They harvest 100% reclaimed yarn and textiles.
Italy	Organizational innovation	WRAD	WRAD is a sustainable fashion brand that is challenging the status quo through sustainable innovation and social change.
Italy + Himalayan Region	Organizational innovation	Himalayan regenerative fashion Living Lab	The Himalayan regenerative fashion Living Lab aims to restore harmony between small local communities in parts of the Himalayas with nature and the environment and, at the same time, to create fashion value chains that are sustainable.
Netherlands	Process innovation	The United Repair Center	The URC offers high-quality clothing repair services, extending the life cycle of clothing items as they strive to create a positive environmental impact.
Netherlands	Organizational innovation	Living Lab Textiles	Living Lab Circular Textiles aims to close the textile loop to the maximum extent possible. Keeping textiles in circulation for as long as possible breaks the prevailing take-make-waste trend in the linear textile chain.
Netherlands	Organizational innovation	Talking Trash	Initiative inside the MSc MADE Living Lab. The project looked into a way to create better local use of post-consumer textile waste, saving transportation and creating circular fashion innovation. The results are a process for a Living Lab way of working and a design theory that can be applied in (local) circular fashion innovation.

Table 3. Cont.

Country	Sector	Name	Description
Romania	Process innovation	REDU	REDU is a textile collection center providing workshops for creating new products from textile waste, repairing and creative recycling workshops, charity bazaars, and swapping.
Spain	Organizational innovation	Ecoalf	Ecoalf is a sustainable and ethical fashion brand that aims to reduce the negative impacts of the fashion industry and the excess use of the planet's natural resources. By integrating breakthrough technology, ECOALF creates clothing and accessories made entirely from recycled materials.
UK	Organizational innovation	Fashion Revolution	FR is the world's largest fashion activism movement, mobilizing citizens, brands, and policymakers through research, education, and advocacy.
UK	Process innovation	Raeburn	RÆBURN is a collaborative, creative fashion studio where daily design meets responsible production, alongside monthly events, discussions, and workshops.

Furthermore, the research indicated how such initiatives work strategically to balance the new sustainability demands of all the stakeholders involved, while also attempting systemic implementation of circular practices within their ecosystem by adopting a multi-disciplinary approach that entails developing and testing solutions that are coherent with the current legislation and facilitate the adoption of new ones, socially required, technologically viable, and financially sustainable.

After examining all 23 mapped companies, 7 European initiatives were selected as case studies for further study. The final case study database was created by including numerous sources from research, documentary corporate reports, scientific articles, trade press reports, and government publications (Table 4).

Table 4. List of the case studies.

Country	Sector	Name
France	Organizational innovation	Tissu Market (Valentino Sleeping Stock)
France	Organizational innovation	LVMH (DARE)
Italy	Organizational innovation	ASTRI
Italy	Process innovation	Simon Cracker
Italy	Process innovation	Tessiture Bevilacqua E Tiziano Guardini
Netherland	Process innovation	The United Repair Center
UK	Process innovation	Raeburn

After the case studies were identified, we also conducted an additional qualitative phase based on interviews with selected representatives of the seven companies previously identified. The data collected in this phase were (1) first-hand data, with interviews conducted directly with available representatives of the selected companies, and (2) second-hand data collected through an additional document research phase. This step allowed us to better profile the companies and identify the various degrees to which they have incorporated the concept from the quadruple helix framework and how they have operationalized it to achieve sustainable quantitative and qualitative development. A dynamic



balance between the four components of open innovation is necessary. This is because economic systems, institutions, governments, and society can largely influence business behavior regarding engagement in open-innovation practices. Specifically, we focused on how companies actively sought to practice sustainable design to reduce the life-cycle impacts of their products, upstream, and to keep the resulting resources in a closed loop by emphasizing interplay among different actors, integration among different operational systems, and cross-functional cooperation between innovation systems.

Starting with the setting described above, the contribution of this study is to codify how higher-level codes are used to create an original quadruple helix model for constructing a fashion closed-loop supply chain. Higher-level codes mean generating important themes from the research and categorizing them according to the methodology proposed by Corbin and Strauss [30]. Such a concept envisions an ecosystem in which advances in raw materials, circular design, ecological processes, and aware consumption are systematically integrated. These four macro-areas were created based on the circular economy's essential notions. They demonstrate how innovation occurs through systemic processes that incorporate all actors in the helix according to their function, competencies, and possibilities. Such methods develop ecosystems to preserve materials and avoid waste by: (1) reusing, elongating the material lifespan; (2) repairing, moving the focus from disposal to care, taking into account how people use products; (3) recycling, creating and manufacturing durable and recyclable items; and (4) refashioning, keeping resources circulating at their full value [31–33].

The following section presents the theorized model and discusses the investigated cases and their fundamental characteristics, presenting them as components of the proposed ecosystem model. The authors acknowledge that these scenarios are not exhaustive, but rather typical of the archetypal operations designed: the actors engaged, their roles, and how their synergies contribute to establishing Sustainable Innovation Fashion Ecosystems. Adopting these examined cases based on the real world is thus functional in illustrating the authors' quadruple helix model for fashion circular innovation.

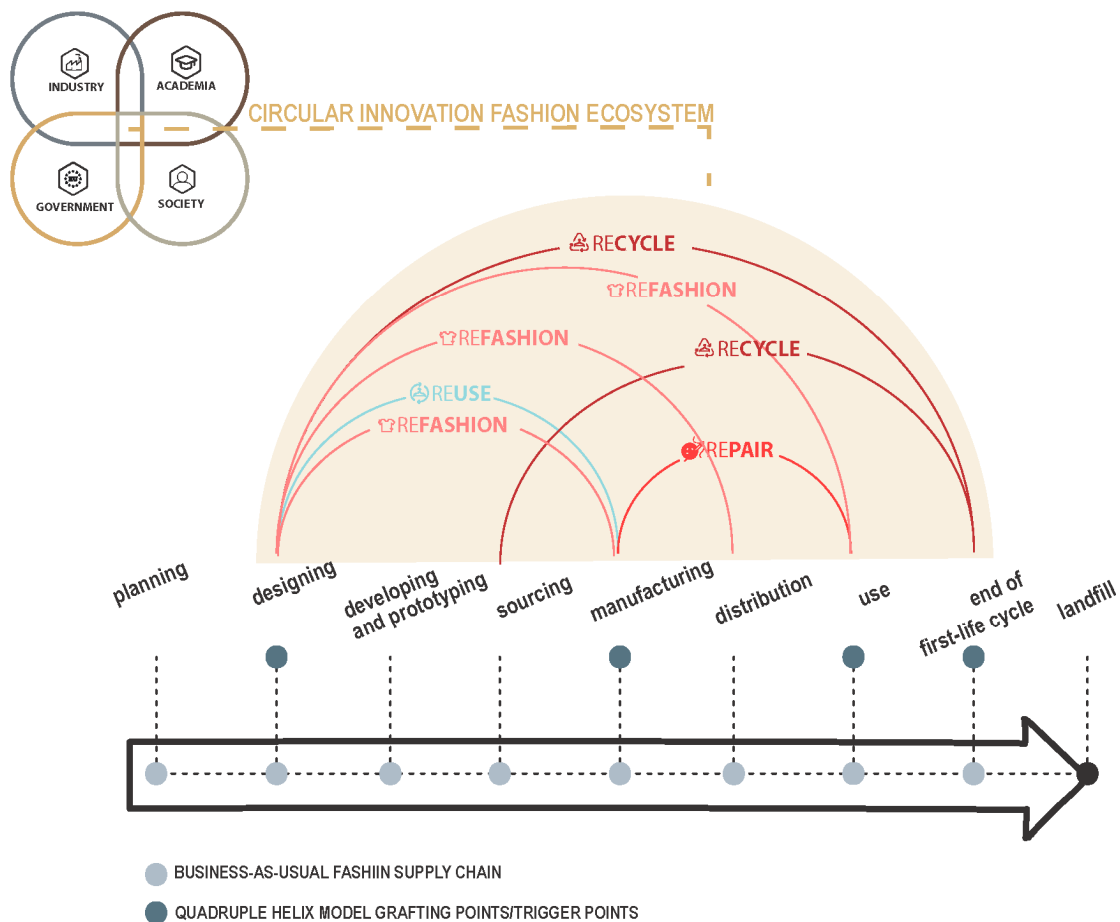
#### 4. Discussion

Based on what has been described so far, this paper presents a conceptual framework for understanding the micro- and macro-dynamics of open innovation in the field of sustainable fashion using a quadruple helix model. This is accomplished by identifying and systematizing four design-driven actions: reuse, repair, refashioning, and recycling, to eliminate the concept of waste to support local ecosystems and the development of a closed-loop fashion supply chain that hacks existing systems by bending the line of business as usual. Companies can act strategically upstream in the supply chain, in the design phase, or downstream, in the waste management phase, to create a cascading effect on all subsequent phases (Figure 2).

The methodology results are presented and discussed here, as well as how the mapped qualitative implementations enable the design of the proposed quadruple helix innovation model for a fashion circular ecosystem. It codifies design directions that could inspire and promote new meaningful perspectives in the field of sustainable fashion.

##### 4.1. Circular Innovation Fashion Ecosystem Model

According to Schuurman [34], in the proposed model, the various actors operate in an innovation system composed of established and organized multidisciplinary networks that promote communication and cooperation, testing the designed solutions in the social context, and involving people in the product or service development process. Such an ecosystem promotes networking, sustaining, and enhancing its technological infrastructure and providing real solutions to modern difficulties from many social, political, entrepreneurial, and research viewpoints.



**Figure 2.** Study model grafting points.

This work aims to demonstrate the potential path to new synergies between the quadruple helix context and the new tools, techniques, and designs available for its actors to tackle various challenges: how they should design, manufacture, and produce to establish a circular fashion ecosystem. Such synergies are shaped on four main paths: new sourcing models, alternative consumption habits, innovative technical know-how, and alternative end-of-life schemes. In the proposed framework, these paths coexist, resulting in an innovation ecosystem where the various acts may occur individually, forming virtuous cycles, and systemically functioning in synergy to optimize the intended circular impact. As a result, actions such as recycling and refashioning can be complementary. The first action provides the raw material for the second. Still, the opposite process can also be generated in which the resources are no longer usable at the end of the refashion action and are thus included in the ecosystem's recycling cycle (Figure 3).

To achieve such a fashion innovation ecosystem, each quadruple helix actor plays a strategic role, according to its capabilities, in each path.

The reuse pathway reimagines the fashion supply chain to enable the creative reuse of fabrics that would otherwise go to waste, transforming the supply to users. This is a four-step path focused on textiles: (1) the collection of textiles from inventories, samples, second choices, and end of production; (2) the cataloging of the collected materials; (3) the creation of a reuse network—promoting partnerships and creating synergies among different actors to give new life to fabrics from the alternative stocks that have been created; and (4) the reinsertion of materials into production/commerce flows—allowing users to purchase reuse materials for their business from the alternative stocks enabled by the ecosystem.

CIRCULAR INNOVATION FASHION ECOSYSTEM

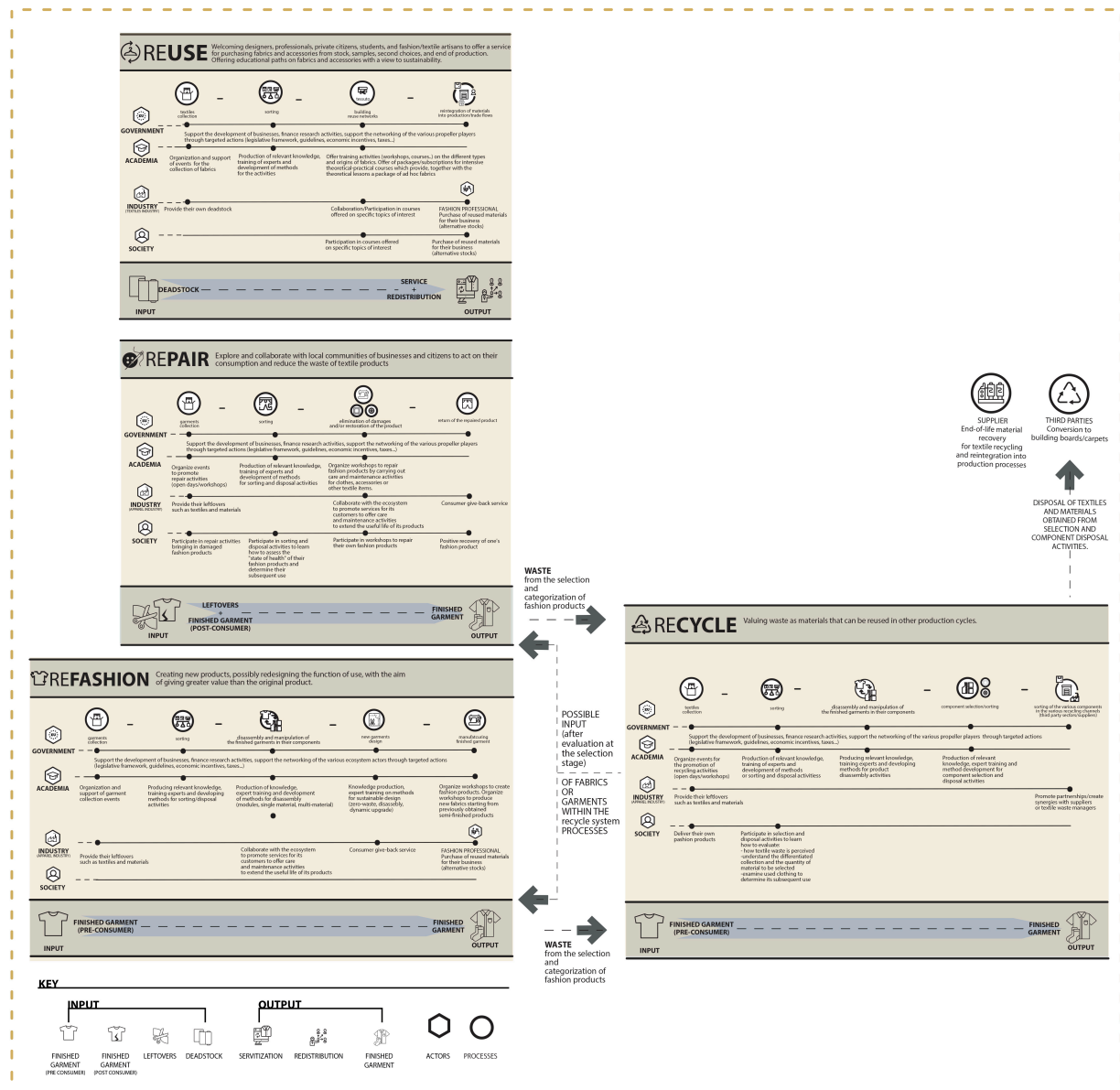


Figure 3. Study model.

The second scenario is a four-step path for repairing. It focused on finished garments and their manufacturing waste according to the following progressive steps: (1) collection from consumers of the finished garments and from industries of their leftovers; (2) sorting a selection and categorization of collected materials; (3) repairing activities as elimination of damages and maintenance of the product; and (4) return of the repaired product as giving users their products back.

The third pathway feeds an input/output cycle based on tissue and material exchange flows. (1) The system receives the waste from the repair and refashioning paths. In the proposed model, the recycling process acquires finished garment waste that is no longer manageable at the end of the other systems' processes and is transformed into new secondary raw material. (2) The system distributes resources within the innovation ecosystem. Following the sorting and disassembly phase, the components appropriate for use in the repair cycles are utilized as repair parts, while the components suitable for use in the refashioning process serve as new raw materials. (3) The system distributes resources outside the innovation ecosystem: Garments and their components, that cannot be recycled

within this ecosystem, are redistributed into two alternative channels: (1) collected by textiles/materials suppliers, who recover the various fabrics and materials, at their end-of-life, for mechanical or chemical recycling; or (2) collected by third parties, who engage in downcycling practices to manipulate the resources that have exhausted their useful life cycle in the fashion industry to be converted into building panels or carpets. This is a five-step process centered on finished clothing: (1) collection of pre-loved items from consumers and finished garments from industries (deadstock, unsold...); (2) sorting—selection and categorization of collected materials; (3) disassembly activities—separating the garments into their various parts; (4) sorting of the disassembled parts—redistribution of the components obtained to the different paths of the ecosystem; and (5) sorting of the components in the separate recycling channels—transfer to the two streams of textiles/materials end-of-life management.

The last path engages the helix actors in refashioning their resources by questioning how designers operate and how they work with their resources. This is a five-step path focused on finished garments: (1) collection of pre-loved items from industries (deadstock, unsold...); (2) sorting—selection and categorization of collected materials; (3) disassembly activities—separating the garments into their various parts; (4) new garments design—designing new garments starting from the components obtained from the disassembly phases and the recycling path; and (5) manufacturing—sewing, cutting, making, processing, repairing, finishing, assembling, or otherwise preparing any garment designed in the previous step.

The following sections examine each of the four archetypical activities through the analysis of case studies. From a circular perspective, these examples demonstrate the fashion ecosystem's approach to innovation using the quadruple helix model. These initiatives encourage developing and implementing circular practices to create a sustainable fashion innovation ecosystem.

#### 4.2. Reuse: Best Practices

The first direction is to create ecosystems that focus on working upstream in the fashion supply chain. By exploiting their spot at the very start of the flow of products and services, the participants work on the sourcing step to build circular supply chains. The fashion system is rethought along this path by restructuring the processes of user access to supplies, production, and logistics [35]. We mapped several existing practices that feature a similar organizational model. For example, LVMH, as part of the DARE (Disrupt, Act, Risk to be an Entrepreneur) project, which is the group's incubator for new ideas, has developed its first online resale platform. This initiative aims to provide another opportunity for high-quality fabrics and leathers that the group's fashion houses can no longer use [36,37]. Another example is the systemic action carried out by various players in the Veneto region on the Venice Fashion Week in May 2020. On this occasion, a group of different players in the fashion system collaborated to stimulate the revitalization of Venetian high craftsmanship and the Venetian fashion system through a product-focused project, specifically the launch of a capsule collection of clothes made from archival materials and textures [38,39]. The actors involved were: fashion designer Tiziano Gardini; nine Venetian manufacturing companies; the ancient Bevilacqua weaving mill, founded in 1499 and active on the Grand Canal; the public and civic networks of VeneziaDavivere; and the Venice Fashion Week event promotion committee. Another company that is making a significant contribution on this front is Valentino. Last year, together with the Tissu Market, they launched the sleeping stock initiative. This collaboration between the Italian Fashion House and the French fabric reseller gives new life to the important textile resources from the Haute Couture and Prêt-à-porter collections archives [40]. This initiative happened in the Tissu Market innovative space dedicated to fashion professions. Designers, individuals, students, and professional dressmakers can buy clothing fabrics and haberdashery items from destocking the prestigious brand at controlled prices and with the possibility of using the knowledge of specialized personnel [31]. Furthermore, this initiative is part of the regulatory framework

that is being defined in France for incentives for criticality in the fashion world [41]. These reuse practices help to reconsider the notion of waste reinserting in market cycle high-quality resources and are a starting point for improving the entire supply chain, which could be actively involved in mapping and reusing the existing materials. While this direction already manages to involve three players in the supply chain—industry, society, and European government—the helix of the academy is still not integrated. The proposal of the model to produce and develop training activities (workshops, courses, etc.) for intensive theoretical–practical courses that provide knowledge for the various actors involved would integrate the missing part and would have the objective of enabling an open-innovation system for the fashion sector capable of bending the fashion supply chain toward an ecosystem that thinks about waste and reuses what is available. In this way, quadruple helix learning could enable innovations through integration between different knowledge and operating systems.

#### *4.3. Repair: Best Practices*

The second direction engages the different quadruple helix actors in building ecosystems that focus on working downstream in the fashion supply chain, involving the consumers. By exploiting this direct link with users and engaging them with products and services, the participants work on developing a notion of care that is opposed to waste to build circular supply chains. The fashion system is rethought along this path by reconsidering the processes of user consumption and industry maintenance of the fashion product [42,43]. This second direction characterizes fashion companies' rising strategies through a service approach that promotes the care for our own or pre-loved goods to prolong their life cycle with a durability perspective applied to the second half of the fashion supply chain—from manufacturing to use. For this path, the study analyzed a single case study, the United Repair Center. The United Repair Center represents a clear example of the theorized model of an open-innovation ecosystem for repairing [44]. Makers Unite and Patagonia launched the project, which collects garments from customers throughout Europe. The Amsterdam-based initiative intends to function as an alternative to clothing that is thrown away by making it easier for manufacturers to incorporate repair into their business model, helping to mitigate the negative impact of the textile industry by promoting circular solutions. Makers Unite, a social impact organization, and Patagonia, an outdoor clothing brand, have established this "United Repair Center" to offer jobs and training to those having problems obtaining work. The Amsterdam Economic Board drew the parties together, and they are funded by a consortium of Dutch investors with a special focus on social impact. The strong national policies supporting sustainability in the fashion industry drove the decision to structure such an ecosystem in this region [45,46]. The initiative seeks to encourage both businesses and consumers to mend garments as a viable option to buy new, prolonging their life and lowering their carbon footprint. Repair practices help give a new semantic meaning to the very concept of waste by giving garment repair services as an alternative to buying new. A multidisciplinary collaboration model between industry, government agencies, society, and educational institutions is proposed in this path, to enable an open-innovation system for the fashion sector capable of hacking the business-as-usual fashion supply chain and making the repair of clothing the new standard. In this direction, quadruple helix learning is enabling innovations by nurturing cross-functional cooperation between innovation systems.

#### *4.4. Recycle: Best Practices*

The third pathway aims to create a systematic and strategic environment based on the exchange of resources between the inside and outside of the designed ecosystem. By exploiting strategic resources' flow and engaging the system actors with waste materials from previous production processes, the participants work on the alternative notion of new instead of virgin to build circular supply chains. Here, the fashion system is reorganized by reconsidering the processes of end-of-life management and industry manufacturing



of fashion products [42,47]. This third direction characterizes fashion companies' rising strategies through a new understanding of raw materials and virgin resources that promotes processes of collecting and changing finished garments so that they can be fully or partially used again. The goal is to extend the life cycle of already processed resources by acting on the entire fashion supply chain. The study also examined a single case study for this path, which contained multiple functional cores to characterize the various acts carried out under the action of recycling, AS.T.R.I. AS.T.R.I. is The Italian recycled textile group, founded to improve Prato, which has been making regenerated fabrics for decades. AS.T.R.I. was born from the determination of a few entrepreneurs in the field that have made recycled and sustainable materials their main features. More than 170 businesses have joined, from workers to passers-by, from old cobblers to raw material merchants, spinning mills, dyers, finishers, and woolen mills. The association's workshops process end-of-life clothing and textile scraps to obtain diverse fibers, from which new recycled yarns are born repeatedly [48]. The study found that end-of-life management of fashion garments is a complicated problem because it is the one with the most essential issues from a regulatory point of view. In fact, for the AS.T.R.I. association, anything that can be recycled in the manufacturing cycle is not waste; thus, it is creating an ecosystem within the Prato region to combat regulations that regard it as such. Accepting these materials into the textile supply chain, as the model presented theorized, is the exact opposite of producing trash., A.S.T.R.I is carrying out some first attempts with some of the different actors in the quadruple helix by involving (1) industry and academia, with Prato's university cluster signing an agreement to increase the sustainability of textile companies in the Prato district through a collaboration to develop research and training activities applied to the textile recycling supply chain, addressing technical aspects related to the circular economy; (2) and industry and government, through several working tables at both the provincial, regional, and national levels set up to support new European eco-design regulations. While these separate initiatives already manage to start positive practices, within the district area, also involving three players in the supply chain—industry, academy, and Italian/European government—the helix of the society is still not integrated. Here, the contribution of the study model is the proposal of strategic actions to integrate the missing component by educating, training, and involving society to participate in sorting and disposal activities to learn how to evaluate textile waste and how this is perceived; understanding the separate collection and the amount of material to sort; and examining used clothing to determine its subsequent use. Such actions could support a paradigmatic change that is also cultural in rethinking our understanding of waste [49]. Such a change could establish an open-innovation system for the fashion sector capable of acting upon the different steps of the supply chain toward an ecosystem that thinks about waste value and works to develop alternatives to virgin resource use. Quadruple helix learning, therefore, is enabling innovations by emphasizing interplay among different actors.

#### *4.5. Refashion: Best Practices*

The last direction aims to build ecosystems throughout the fashion supply chain. By exploiting the grafting point at the beginning and end of the processes, the different quadruple helix actors work on designing, manufacturing, and end-of-life steps to build a circular supply chain. The fashion system is reimaged in this path by rethinking the processes of designer manipulation of resources [50]. Different brands operate according to this work stream, such as the Italian Simon Cracke [51]. The brand was born from Simone Botte's idea as an upcycling clothing line that provides a second opportunity for high-quality resources from deadstock to end-of-production items. These raw materials, which are considered waste, are transformed into garments that are one-of-a-kind pieces, characterized by the disassembly and reassembly of the starting garments designed and made with a total upcycling approach, where nothing new is used and everything is sourced locally. Another example is the British designer Cristopher Raeburn, who founded the eponymous brand that advocates for conscientious and intelligent fashion design [52,53].



His RÆMADE approach, in particular, has led the way in refashioning leftover fabrics and clothes to produce unique and functional pieces. Its design-based solutions draw on different sectors, its raw materials ranging from wool field jackets to nylon parachute canopies. These starting elements and materials are disassembled and manipulated to obtain a new garment with a different function from the original. They work on the principle that upcycling garments rather than throwing them away is a simple method for everyone to decrease their effect and be more responsible—an element that has been at the heart of their business since its inception. The goal is to motivate people to look in their closets and try to refashion their garments, starting a paradigmatic change in manufacturing and consumption habits through collaboration and knowledge exchange. These refashion practices support a change in the notion of waste, advocating for a new understanding: reintroducing into the manufacturing cycle high-quality resources by redesigning them. This design action is the initial step for transforming the entire supply chain, which could be actively involved in hacking and refashioning the existing materials. These examples demonstrate how single actors carry out refashioning practices along the supply chain but how these initiatives remain isolated. While this direction already manages to involve two players in the quadruple helix model—industry and society—the branches of academia and government are still not integrated. For this, we systematize the existing resources in the model by bringing all the actors into the system, leveraging their contributions. Academia is strategic to combine the theoretical dimension with the practical one by producing new knowledge, methods, and tools, training professionals, and offering manufacturing workshops. Governments that previously focused on regulation control and standardization are transforming their role for facilitating collaboration among universities, industries, and society and helping to create knowledge and stimulate demand, thus promoting new frameworks for boosting the fashion industry and setting international standards for circular practices. The development of such a system would act along the supply chain by allowing the development of multi-sector strategies that can enable the use of used or waste materials, components, and products, or create a product of greater value than its component elements toward a closed-loop system by design [54,55]. The last direction is enabling innovations by combining the key concepts of quadruple helix by supporting interplay among different actors, fostering integration among different operational systems and promoting for cross-functional cooperation between closed-loop innovation systems.

## 5. Study Limitations and Future Research

The article discussed a quadruple helix-based architecture for nurturing sustainable innovation ecosystems in European fashion enterprises. A model like this encourages the implementation of circular practices toward a closed-loop supply chain by serving as a platform for communal invention and development, as well as a source of knowledge and a testbed for novel products, services, systems, and solutions [56]. As a result, many fashion firms are changing their organizational structures by including collaboration and synergistic initiatives to strengthen their circular advantage. Consequently, as various scholars have discussed [57–60], a systemic innovation approach in which all stakeholders—in products, services, or applications—participate directly in the development process enables the implementation of new ecosystems. The authors contribute to this debate by proposing a framework in which product design coexists at the intersection of policy, social, scientific, and technological recognition and is thus integrated into a collaborative act of circular solutions, which in turn becomes a platform for dialogue that re-signifies resources, textiles, and materials with a multi-disciplinary approach based on collaboration with the various actors involved in the production and use of fashion. Specifically, as supported by the cases presented here, the model provides some insights into the potential of circular synergies to close the resources loop in an open-innovation ecosystem. With the help of other actors—customers, competitors, collaborators, complements, and all other categories—that function as one and share common goals and purposes, such a system may assist an

industrial transition to circularity in the fashion sector. The proposed framework illustrates how this is possible, along the supply chain, whether we are moving:

- *upstream*, through a semantic redetermination of the concept of trash by enabling the design of generating no waste because everything is shared, mended, reused, or recycled
- *downstream*, as in the valorization of waste into secondary raw materials that can be reused within the ecosystem itself or in other production cycles after its useful life as a fashion resource has ended
- *along the supply chain*, focusing on the identified grafting points to create a cascade effect, such as adopting refashion solutions to hack parts of obsolete products into new items or initiatives, such as providing new sourcing opportunities, as well as establishing synergies to provide resources for repair services or manufacturing.

Such activities can significantly contribute to establishing a circular and sustainable fashion system.

The authors would like to address several limitations of this study. Recognizing the data's limited scope, this work does not aim to suggest new theories but rather contributes to the existing ones by interpreting and codifying the available data. Nonetheless, it delivers complementary insights that indicate and cultivate a specific perspective to grasp fashion's closed-loop journey in an open-innovation quadruple helix-based ecosystem [61,62]. This research was carried out within the setting of the developed European economy's fashion sector, which has distinct legislative, social, institutional, and economic features that are pushing toward green and circular initiatives [11,63]. For this reason, concentrating specifically on Europe seemed appropriate, given that some of the studies investigated for this publication have their roots on this continent. The mapping of the examples highlighted how the various realities have developed or are developing a solid awareness of circularity challenges and a commitment to improving efforts and actions. As a result, the results should be understood considering this paradigm. The study of the proposed model revealed how systemic and open knowledge exchange and application of different competencies enable disassociating sustainable innovation from the concept of resource exploitation by emphasizing the importance of offering material and meaningful alternatives to the very notion of "waste" and, consequently, "new". Through the diversity in the organizational differences of the quadruple helix players, such change in meanings and practices fosters the formation and access to new ecosystems.

According to the fashion industry perspective used in this work, the companies in this study displayed the traits required to interact within an existing context to acquire the resources, skills, and competencies needed to advance toward a circular quadruple helix-based ecosystem:

1. These players encounter cyclical dynamics between market–open, internal, and societal–open innovation at the macro-dynamics level [61]. In this context, fashion actors are confronted with new combinations and creative connections between technology and society, engaging users who become market sources, resulting in startups and entrepreneurs creating new combinations between technology and the open market through solutions developed with society. The outcomes of these exchanges feed internal open innovation via partnerships and the many open-innovation channels. The constant equilibrium of these three open inventions fuels the ecosystem's circular growth.
2. At the micro-dynamic level, open innovation refers to the cyclical dynamics between open innovation, complex adaptive systems, and evolutionary change [64]. Suppose the complexity of supply and demand operations, roles, and exchanges is strategically controlled through a systemic open-innovation approach. In that case, fashion actors must operate to manage the complexity of exchanges, material, and workflows to achieve a complex adaptive system through creative development at the level of evolutionary change.

Future studies should investigate the elements that influence organizational design characteristics, which could lead to various research paths to explore how sustainability can be achieved through open innovation in the circular fashion supply chain:

1. Open innovation entails numerous actors, from policy to business and individuals, co-creating knowledge in different spheres. The phenomenon should be considered a dynamic and multi-disciplinary process instead of a closed and static behavior that entails working in sealed compartments.
2. Obstacles to adopting a systemic and share model where all the participants are involved along the different initiatives' steps.
3. Considering the context in which fashion companies operate, that of industry 4.0, and from what has emerged from various cases, the role of the digital medium as an enabler of a positive circular change, toward sustainability, must be further explored.
4. The effect of operating within a quadruple helix-based innovation model, for example, in networking or, from a company perspective, operating in all stages of the knowledge and technology transfer process.

Additionally, future innovations—influenced by the data from the research—could be feasible for fashion-driven innovation ecosystems and be consistent with the existing European policy recommendations [3]. The EU Commission is currently applying plans to adopt the new frameworks for sustainable product development. The EU framework will establish eco-design standards to make sure fashion products are circularly compatible, promote product-as-a-service business models, supply circular materials and manufacturing processes, and foster international collaboration for greater transparency, as well as offer recommendations for separate textile waste collection to encourage innovation in textile sorting, reuse, and recycling. Such initiatives can be supported by the EU fashion sector's quadruple helix innovation model. They can be used to support sustainable development theories in the existent and future EU policy environment.

## 6. Conclusions

In conclusion, ecosystem innovation is a space to solve contemporary challenges, such as tackling climate change and other global challenges, such as biodiversity loss, pollution, and waste, by bringing together various stakeholders for collaboration and collective ideation [15]. Such systems could feed effective circular practices, in the fashion sector, through the creation of joint initiatives that, through design-driven actions—reuse, repair, reuse, and recycle—involve the different actors, in their separate ways, to eliminate the concept of waste to support local ecosystems toward creating a closed-loop chain to achieve the ultimate goal of the circular economy by decoupling economic activity from the consumption of finite resources [65].

This study provides an initial reference framework for how quadruple helix actors might be involved and work together to implement circular solutions throughout the fashion supply chain. The innovation ecosystem that emerges from such an environment could be implemented based on inherent capabilities, technological skills, and organizational strategies that are unique to specific independent strategies. According to the aforementioned, the framework presented is now being evaluated to develop the operational model of a new Living Lab for Circular Fashion under the MUSA project. MUSA—Multilayered Urban Sustainability Action is an innovation ecosystem funded by the Ministry of University and Research within the framework of the National Recovery and Resilience Plan (PNRR, Mission 4, Component 2, Investment 1.5). The project is part of Spoke 3—Ecosystem. The goal is to set up indicatively three to four Living Labs on issues related to recovery and recycling, from a circular economy perspective, applied primarily, but not exclusively, to packaging, textiles, construction materials, batteries, and electrical and electronic equipment. This initiative aims to create an experimentation infrastructure that fosters co-creation and open innovation within the fashion supply chain. It strategically nurtures collaboration among fashion industry actors, companies or startups to develop, test, and establish more

radical innovations capable of transforming waste into new resources and enabling circular contexts and ecosystems.

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## References

1. European Commission. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions—The European Green Deal*; COM(2019) 640 Final; European Commission: Brussels, Belgium, 2019. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640> (accessed on 28 August 2023).
2. Ortega-Gras, J.J.; Bueno-Delgado, M.V.; Cañavate-Cruzado, G.; Garrido-Lova, J. Twin transition through the implementation of industry 4.0 technologies: Desk-research analysis and practical use cases in Europe. *Sustainability* **2021**, *13*, 13601.
3. European Commission. *The European Green Deal*; European Commission: Brussels, Belgium, 2019. Available online: [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en) (accessed on 28 August 2023).
4. Faivre, C.; Rückert, D.; Veugelers, R.; Weiss, C.T. The Green and Digital Twin Transition: EU vs US Firms. *Intereconomics* **2023**, *58*, 56–62.
5. European Green Deal: Commission Proposes Transformation of EU Economy and Society to Meet Climate Ambitions. Available online: [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_21\\_3541](https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541) (accessed on 2 August 2023).
6. Wilgosh, B.; Sorman, A.H.; Barcena, I. When two movements collide: Learning from labour and environmental struggles for future Just Transitions. *Futures* **2022**, *137*, 102903. [CrossRef]
7. European Environment Agency. *Sustainability Transitions: Policy and Practice*; EEA Report No 9/2019; European Environment Agency: Copenhagen, Denmark, 2019.
8. The Twin Green & Digital Transition: How Sustainable Digital Technologies Could Enable a Carbon-Neutral EU by 2050. Available online: [https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29\\_en](https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29_en) (accessed on 1 August 2023).
9. Bianchini, S.; Damioli, G.; Ghisetti, C. The environmental effects of the “twin” green and digital transition in European regions. *Environmental and Resource Economics* **2023**, *84*, 877–918. [CrossRef] [PubMed]
10. Muench, C.; Benz, L.A.; Hartmann, E. Exploring the circular economy paradigm: A natural resource-based view on supplier selection criteria. *J. Purch. Supply Manag.* **2022**, *28*, 100793. [CrossRef]
11. EU Strategy for Sustainable and Circular Textiles. Available online: [https://environment.ec.europa.eu/strategy/textiles-strategy\\_en](https://environment.ec.europa.eu/strategy/textiles-strategy_en) (accessed on 2 August 2023).
12. Hossain, M.; Leminen, S.; Westerlund, M. A systematic review of living lab literature. *J. Clean. Prod.* **2019**, *213*, 976–988. [CrossRef]
13. EURATEX. *Facts and Key Figures 2022*; EURATEX, Economic and Statistics: Brussels, Belgium, 2022.
14. Afonso, O.; Monteiro, S.; Thompson, M. A growth model for the quadruple helix. *J. Bus. Econ. Manag.* **2012**, *13*, 849–865. [CrossRef]
15. European Network of Living Labs. Available online: <https://enoll.org/> (accessed on 1 August 2023).
16. Paskaleva, K.; Evans, J.; Watson, K. Co-producing smart cities: A Quadruple Helix approach to assessment. *Eur. Urban Reg. Stud.* **2021**, *28*, 395–412. [CrossRef]
17. Durán-Romero, G.; López, A.M.; Beliaeva, T.; Ferasso, M.; Garonne, C.; Jones, P. Bridging the gap between circular economy and climate change mitigation policies through eco-innovations and Quintuple Helix Model. *Technol. Forecast. Soc. Change* **2020**, *160*, 120246. [CrossRef]
18. Hysa, E.; Kruja, A.; Rehman, N.U.; Laurenti, R. Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. *Sustainability* **2020**, *12*, 4831. [CrossRef]
19. Nguyen, H.T.; Marques, P. The promise of living labs to the Quadruple Helix stakeholders: Exploring the sources of (dis)satisfaction. *Eur. Plan. Stud.* **2022**, *30*, 1124–1143. [CrossRef]
20. Baxter, P.; Jack, S. Qualitative case study methodology: Study design and implementation for novice researchers. *Qual. Rep.* **2008**, *13*, 544–559. [CrossRef]
21. Johansson, R. On Case Study Methodology. *Open House Int.* **2007**, *32*, 48–54. [CrossRef]



22. Taratori, R.; Rodriguez-Fiscal, P.; Pacho, M.A.; Koutra, S.; Pareja-Eastaway, M.; Thomas, D. Unveiling the Evolution of Innovation Ecosystems: An Analysis of Triple, Quadruple, and Quintuple Helix Model Innovation Systems in European Case Studies. *Sustainability* **2021**, *13*, 7582. [CrossRef]
23. Compagnucci, L.; Spigarelli, F.; Coelho, J.; Duarte, C. Living Labs and user engagement for innovation and sustainability. *J. Clean. Prod.* **2021**, *289*, 125721. [CrossRef]
24. Metcalfe, A.S. Examining the trilateral networks of the triple helix: Intermediating organizations and academy-industry-government relations. *Crit. Sociol.* **2010**, *36*, 503–519. [CrossRef]
25. Yin, R.K. *Case Study Research: Design and Methods*, 4th ed.; Sage: Thousand Oaks, CA, USA, 2012.
26. Erasmus+ Programme of the European Commission (2019–2021). FashionSEEDS—Fashion Societal, Economic & Environmental Design-led Sustainability. Available online: <https://www.fashionseeds.org/> (accessed on 28 August 2023).
27. European Commission, COSME Programme (2018–2021). DeFINE Developing a Fashion-Tech Innovation Network for Europe. Available online: <https://www.define-network.eu/> (accessed on 28 August 2023).
28. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship, and SMEs. *Support Report Mapping Sustainable Fashion Opportunities for SMEs*; European Commission: Brussels, Belgium, 2019. [CrossRef]
29. D'Itria, E. Driving Sustainability in Fashion through Design: Experimenting with the Role of Design in the Development of a Circular Fashion Supply Chain Model. Ph.D. Thesis, Politecnico di Milano, Milano, Italy, 2022. Unpublished.
30. Corbin, J.M.; Strauss, A. Grounded theory research: Procedures, canons, and evaluative criteria. *Qual. Sociol.* **1990**, *13*, 3–21. [CrossRef]
31. Barosi, E.; D'Itria, E.; Vacca, F. Left (L) overs: Semanticizing waste in the Fashion System. *OFFICINA\* J.* **2023**, *41*, 62–71.
32. Puntillo, P.; Gulluscio, C.; Huisingh, D.; Veltri, S. Reevaluating waste as a resource under a circular economy approach from a system perspective: Findings from a case study. *Bus. Strategy Environ.* **2021**, *30*, 968–984. [CrossRef]
33. Stahel, W.R. The circular economy. *Nature* **2016**, *531*, 435–438. [CrossRef] [PubMed]
34. Schuurman, D.; De Moor, K.; De Marez, L.; Evens, T. Investigating user typologies and their relevance within a living lab-research approach for ICT-innovation. In Proceedings of the 43rd Hawaii International Conference on System Sciences, Honolulu, HI, USA, 5 August 2010.
35. Buchel, S.; Hebinck, A.; Lavanga, M.; Loorbach, D. Disrupting the status quo: A sustainability transitions analysis of the fashion system. *Sustain. Sci. Pract. Policy* **2022**, *18*, 231–246. [CrossRef]
36. Belck, R.W. Luxury consumption and COVID-19. In *The Future of Luxury Brands: Artification and Sustainability*; Joy, A., Ed.; Walter de Gruyter GmbH: Berlin, Germany, 2022; pp. 19–35.
37. Rognoli, V.; Petreca, B.; Pollini, B.; Saito, C. Materials biography as a tool for designers' exploration of bio-based and bio-fabricated materials for the sustainable fashion industry. *Sustain. Sci. Pract. Policy* **2022**, *18*, 749–772. [CrossRef]
38. UK-Italy: Lessons in Sustainable Fashion alla Venice Fashion Week. Available online: <https://www.vogue.it/vogue-talents/article/uk-italy-lessons-in-sustainable-fashion-venice-fashion-week-2019> (accessed on 30 July 2023).
39. Balagtas, C.; Stanley, A.E.; Le Troquer, F.; Coste-Manière, I. An Old Approach Sees Major Revival: Local Textiles Go Global. In *Sustainable Approaches in Textiles and Fashion: Consumerism, Global Textiles and Supply Chain*; Muthu, S.S., Ed.; Springer Nature: Singapore, 2022; pp. 183–203.
40. Valentino Sleeping Stock. Available online: <https://www.valentino.com/it-it/creating-shared-value/planet/valentino-sleeping-stock> (accessed on 30 July 2023).
41. Peleg Mizrachi, M.; Tal, A. Regulation for promoting sustainable, fair and circular fashion. *Sustainability* **2022**, *14*, 502. [CrossRef]
42. Dissanayake, D.G.K.; Weerasinghe, D. Towards circular economy in fashion: Review of strategies, barriers and enablers. *Circ. Econ. Sustain.* **2022**, *2*, 22–45. [CrossRef]
43. Gwilt, A. *A Practical Guide to Sustainable Fashion*, 2nd ed.; Bloomsbury Publishing: London, UK, 2020.
44. United Repair Center. Available online: <https://unitedrepaircentre.com/> (accessed on 2 August 2023).
45. Infographic: Extended Producer Responsibility for Textiles. Available online: <https://www.government.nl/documents/publications/2023/05/01/infographic-extended-producer-responsibility-for-textiles> (accessed on 2 August 2023).
46. Lavanga, M. A Spotlight on: Sustainable fashion in the Netherlands. In *Global Perspectives on Sustainable Fashion*; Gwilt, A., Payne, A., Ruthschilling, E.A., Eds.; Bloomsbury Academic Publishers: London, UK, 2019; pp. 97–99.
47. Niinimäki, K.; Karell, E. Closing the loop: Intentional fashion design defined by recycling technologies. In *Technology-Driven Sustainability: Innovation in the Fashion Supply Chain*; Vignali, G., Reid, L.F., Ryding, D., Henninger, C.E., Eds.; Springer Nature: Singapore, 2020; pp. 7–25.
48. A.S.T.R.I. Available online: <https://astrirecycling.it/riciclo/> (accessed on 2 August 2023).
49. Wagner, M.M.; Heinzl, T. Human perceptions of recycled textiles and circular fashion: A systematic literature review. *Sustainability* **2020**, *12*, 10599. [CrossRef]
50. Marques, A.D.; Moreira, B.; Cunha, J.; Moreira, S. From waste to fashion—A fashion upcycling contest. *Procedia CIRP* **2019**, *84*, 1063–1068. [CrossRef]
51. Simon Cracker. Available online: <https://www.simoncrackermilano.com/> (accessed on 30 July 2023).
52. Available online: <https://www.raeburndesign.co.uk/> (accessed on 30 July 2023).
53. Zhi, Y. The Upcycling and reconstruction of garments and fabrics. *Art Des. Rev.* **2021**, *10*, 72–102. [CrossRef]

54. Sung, K. Understanding upcycling and circular economy and their interrelationships through literature review for design education. *Proc. Des. Soc.* **2023**, *3*, 3721–3730. [[CrossRef](#)]
55. Sung, K. Sustainable production and consumption by upcycling: Understanding and scaling-up niche environmentally significant behavior. Doctoral Dissertation, Nottingham Trent University, Nottingham, UK, 2017.
56. Leminen, S. Living Labs as Open Innovation Networks—Networks, Roles, and Innovation Outcomes. Doctoral Dissertation, Aalto University, Espoo, Finland, 2015.
57. Majumdar, A.; Garg, H.; Jain, R. Managing the barriers of Industry 4.0 adoption and implementation in textile and clothing industry: Interpretive structural model and triple helix framework. *Comput. Ind.* **2021**, *125*, 103372. [[CrossRef](#)]
58. Midgley, G.; Lindhult, E. A systems perspective on systemic innovation. *Syst. Res. Behav. Sci.* **2021**, *38*, 635–670. [[CrossRef](#)]
59. Bertassini, A.C.; Zanon, L.G.; Azarias, J.G.; Gerolamo, M.C.; Ometto, A.R. Circular Business Ecosystem Innovation: A guide for mapping stakeholders, capturing values, and finding new opportunities. *Sustain. Prod. Consum.* **2021**, *27*, 436–448. [[CrossRef](#)]
60. Miller, K.; McAdam, R.; McAdam, M. A systematic literature review of university technology transfer from a quadruple helix perspective: Toward a research agenda. *RD Manag.* **2018**, *48*, 7–24. [[CrossRef](#)]
61. Yun, J.J.; Liu, Z. Micro-and macro-dynamics of open innovation with a quadruple-helix model. *Sustainability* **2019**, *11*, 3301. [[CrossRef](#)]
62. Anttonen, M.; Lammi, M.; Mykkänen, J.; Repo, P. Circular economy in the triple helix of innovation systems. *Sustainability* **2018**, *10*, 2646. [[CrossRef](#)]
63. ECAP—The European Clothing Action Plan. Available online: <http://www.ecap.eu.com/> (accessed on 2 August 2023).
64. Yun, J.J.; Won, D.; Park, K. Dynamics from open innovation to evolutionary change. *J. Open Innov. Technol. Mark. Complex.* **2016**, *2*, 1–22. [[CrossRef](#)]
65. MacArthur, E. Towards the circular economy. *J. Ind. Ecol.* **2003**, *2*, 23–44.

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