DIGITAL ADVANCED DESIGN

TRANSITIONAL INDUSTRIAL APPROACHES FOR SUSTAINABLE INNOVATION

edited by
Flaviano Celaschi
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Summary

DIGITAL DESIGN FOR CIRCULAR MATERIALS

DIGITAL WASTE PASSPORT. DESIGN A CROSS-SECTORIAL PLATFORM OF SERVICES TO FACILITATE TEXTILE SMES OF MADE IN ITALY IN ACHIEVING TRACEABILITY AND CIRCULARITY

Debora Giorgi, Marco Bellandi**, Claudia Morea*, Chiara Rutigliano*, Luca Incrocci*, Matteo Bertelli*, Elizaveta Stark***

1. Introduction

The research addresses the need for SMEs in the textile and fashion industry, particularly those representing Made in Italy, to align with new European regulations on traceability and circularity. The research aims to propose an ecosystem of services to help SMEs remain competitive by promoting traceability at the End-of-Life stage and expanding cross-sectoral market opportunities for using recycled materials.

In particular, the **opportunities offered by the Digital Product Passport** and traceability technologies to support the transition to circular supply chain and recycling scenarios had been explored. The Digital Product Passport brings up new levels of traceability and transparency along the entire supply chain through the collection, classification, comparison, and transmission of data among all actors in the textile product life cycle, as required by European legislation. However, there are still open issues related to the textile waste traceability and its entry into new life cycles. Therefore, the main goal of the research is the creation of an ecosystem of services designed to support and guide clusters of SMEs, start-ups, and research centers in textile districts towards a circular and sustainable transition through cross-sectoral solutions. Key research areas include secondary materials, textile recycling technologies, regulations, and SME readiness for these changes. The project presented here provides the definition of a digital platform to support ecodesign in the textile sector starting from the integration and implementation of current digital tools for the textile and fashion industry.

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2. Research framework and methodology

The research has been structured on three phases, the first explorative of specific topics, the second co-design phase characterized by stakeholders' involvement, and the third phase of infrastructure design and prototype in collaboration with Italtel spa.

In the first phase a State of Art related to four specific research topics was conducted, specifically: 1) New European regulation for a more sustainable textile industry, 2) technologies for traceability (DPP), 3) textile recycling technologies and machineries 4) cross-sectoral market opportunities 5) District and Circular Business Model.

For the State of the Art was conducted a Desk and Field research. The Desk research included: Literature Review, using tools such as Google Scholar and Scopus; Analysis of both sectoral and cross-sectoral markets; Analysis of regulations and directives regarding the project issues, including possible cross-sectoral applications, Innovative technologies, Stakeholders map and Ecosystem Map. The Field Research included: Meetings with key stakeholders (trade associations, informal networks, industry and technology companies, including startups, policy makers); participation in major industry events interviews; focus groups; company visits; questionnaires.

The outcomes of this phase were the identification of gaps between regulations and companies' needs, the Mapping of the stakeholders Ecosystem around the topic at local level (Prato Textile District) and a Concept proposition for services platform.

The second phase had the intention to verify with the possible stakeholders the gaps and needs identified and validate the platform concept with the proposition of a service ecosystem service for the Prato District. The research involved the participation of various stakeholders operating in the textile industry at regional level in a co-design workshop, preceded by preliminary interviews, questionnaires, and company visits.

This collaborative approach allowed to highlight cross-sectoral opportunities, bringing together diverse expertise and activating collaborations across the entire supply chain: a co-design process brought together stakeholders from various parts of the value chain, including manufacturers, recyclers, technology and machineries suppliers, industry associations. The applica-

tion of co-design methodologies facilitated the identification of opportunities that may not be apparent from a single perspective (Pirinen, 2016). Furthermore, from the stakeholders' in-depth knowledge of production processes, innovative solutions emerged, leading to further collaborations and requests for the definition of tailored tools. For example, a technology supplier could collaborate with a recycler to develop a new method for identifying the composition of mixed material blends, facilitating more effective recycling (Tukker, 2015).

Based on the outcomes of the previous two phases, the third phase concerned the experimental design of a services infrastructure aimed at supporting clusters of SMEs. Specifically, three specific objectives were identified and prioritized in order of importance in relation to the setup of the services infrastructure:

- To support companies in the data collection of waste—secondary raw materials;
- To promote digital and accessible sectoral specific tools for traceability and ecodesign;
- To facilitate a network creation based on sectoral and cross-sectoral recycling opportunities.

Methodologies from Service Design, UI/UX Design were applied.

3. Results discussion

3.1. European Regulation for textile recycling

Annually, the EU discards 5.8 million tonnes of textiles, averaging 11 kg per person, while globally, a truckload of textiles is incinerated or discarded every second (Kew, 2023). To mitigate this, EU's Green Deal, Circular Economy Action Plan, and Industrial Strategy prioritize the textile sector for reducing environmental impacts. Moreover, the Strategy for Sustainable and Circular Textiles envisions an industry producing durable, recyclable, and non-toxic products by 2030.

Mandatory textile waste collection across Europe from 2025 presents both challenges and opportunities, particularly in recycling mixed fibers like wool-polyester. Additionally, the prolif-

eration of certification schemes has generated confusion, often leading to misleading sustainability claims.

In response, EURATEX proposed European Textile Recycling Hubs (ReHubs) to align with EU circular economy goals by processing large volumes of textile waste and fostering industrial symbiosis, though concerns about material quality and data accuracy persist. While concerns have been raised regarding the low quality of output materials and insufficient data on input materials, ReHubs have the potential to lower waste management costs, enhance industry collaboration, and foster employment.

The revision of the Waste Framework Directive seeks to standardize Extended Producer Responsibility (EPR) for textiles, ensuring producers manage post-consumer waste. With 25-40% of textiles discarded during manufacturing and less than 1% reused, textile recycling in the EU remains limited, with only 20% of materials downcycled (JRC, 2021). The 2023 update to the REACH directive introduces sustainability criteria for chemicals used in textile production. Enhanced traceability technologies are needed to preserve the quality of secondary raw materials and increase cross-sector market opportunities.

3.2. Technology for circularity

Traceability technologies like blockchain can improve supply chain transparency, and the proposed Ecodesign Directive amendment encourages their adoption, despite cost and regulatory challenges. Directive 2024/825/EU, set for September 2026, aims to combat greenwashing by banning invalid certifications. Effective communication across supply chains, from production to recycling and reuse, is crucial for sustainability.

Digitalization is key to achieving circular supply chains, with major brands adopting technologies to share product data. However, concerns remain about regulation, privacy, and affordability, especially for SMEs. The Ecodesign for Sustainable Products Regulation (ESPR) introduces the Digital Product Passport (DPP), requiring public disclosure of product circularity and ecodesign data. DPPs could provide information on material composition, production processes, and ownership history, aiding regulatory compliance and informed consumer decisions. These tools are pivotal for enhancing product durability, recyclability, and transparency in the fashion industry.

However, integrating DPPs into secondary raw materials remains a challenge. Two prominent issues that arose here: a) textile industry's global and complex value chain, which is heavily reliant on outsourcing and often lacks transparency; b) pressure from consumer groups, regulations, and other stakeholders are driving technological improvements.

Our research explores the integration of digital solutions for sharing crucial information related to recycling, reuse, repair, and disassembly data throughout the supply chain, focusing on textile waste traceability and management. It examines enabling technologies like Blockchain, IoT, DPPs, and Digital Twins, with a particular focus on identifying mandatory and optional data for DPP implementation.

The research highlighted persisting challenges, especially for SMEs, which face excessive costs, long payback periods, and regulatory uncertainty. While large companies can invest in these technologies, SMEs struggle with the complexities of data sharing. Despite these challenges, DPPs offer significant potential for SMEs by helping them comply with traceability regulations, enhance their reputation, and access circular economy markets. Finally, effective DPP integration could improve the eco-design.

Current DPP initiatives lack unified standards, and different sectors, like battery recycling, complicate the landscape further. It remains unclear whether a single document or multiple passports will be required for the same product. Success will depend on ensuring a) data security and trust; b) technologies accessibility to SMEs; c) fostering stakeholder collaboration to develop standardized protocols.

3.3. Textile recycling types and cross-sectoral opportunities

End-of-life textile treatment is divided into pre-consumer and post-consumer waste. Pre-consumer waste, generated during production (e.g., offcuts, fibers), is classified in the European Waste Catalogue (CER, 2013). Recycling multi-material fiber blends, especially those containing elastane, is technically challenging and requires advanced technologies like AI, Near-Infrared Spectroscopy, and thermo-chemical processes. Non-reusable textiles often end up exported and incinerated in landfills.

Effective management involves optimizing production to reduce material use through centralized collection, waste analysis, and machinery adjustments.

Mechanical recycling is the most common method, though it often requires blending with virgin materials. Chemical and biochemical recycling methods (e.g., feedstock, enzymatic processes) offer potential but face environmental and adoption hurdles. Simpler methods, like composting and converting textiles into cleaning rags, offer limited sustainability benefits.

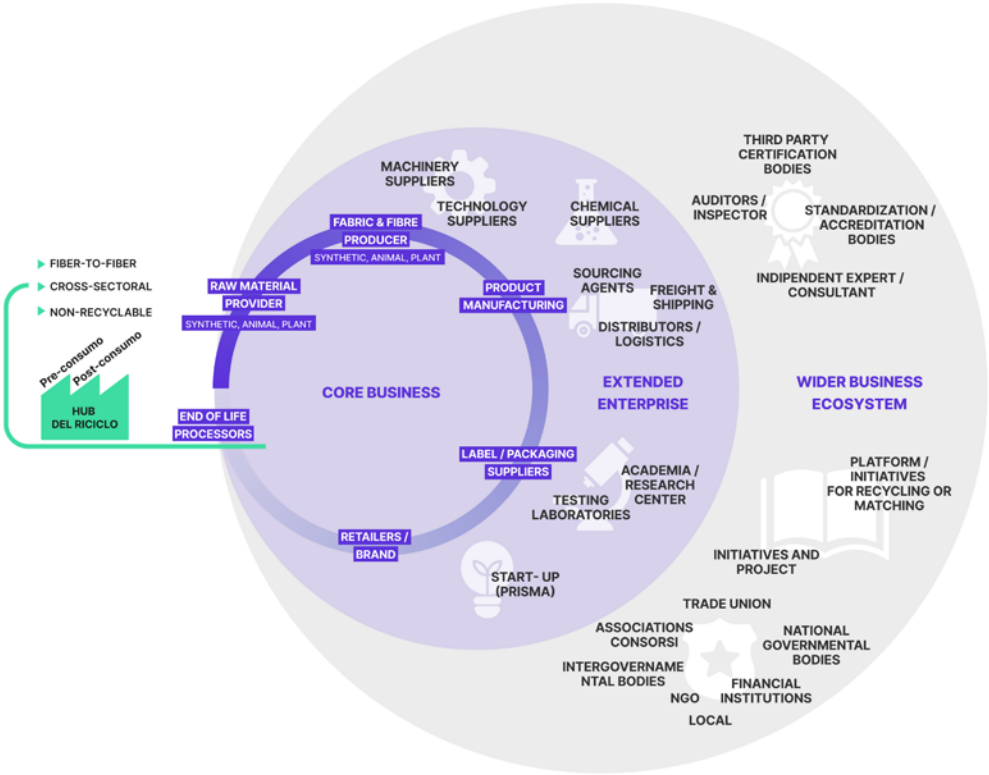
Recycled textiles are used in industries such as automotive, construction, and packaging, necessitating cross-sector collaboration and regulatory adherence. However, meeting diverse industry standards remains a challenge, prompting the development of complex assessment scales for recycled product feasibility across sectors. Regions like Prato excel in mechanical recycling, processing up to 36,000 tons annually, though challenges such as chemical contamination and meeting regulatory standards persist.

The complexity of textile recycling highlights the need for advanced technologies and improved regulatory frameworks. Digital tools, such as the Digital Product Passport, can enhance material traceability, regulatory compliance, and sustainability in the textile industry.

3.4. Textile-clothing districts and Circular Business Models

Europe, particularly Italy, has a rich history in the textile and clothing industries, shaped by the development of specialized clusters in defined local areas. These clusters comprise networks of firms engaged in related stages of value chains, supported by complementary services and institutions. In Italy, some clusters are led by large firms, while others consist solely of SMEs, such as the renowned Prato district (Dei Ottati, 2009).

Italian textile-clothing SME clusters thrived in the late 19th century due to a combination of: a) networked industrial efficiency (economies of specialization among networks of SMEs); b) artisanal care preserved in some SMEs (enhancing quality, image, and variety of products); c) and the supporting role of socio-cultural and institutional relations embedded in the place (collective infrastructures and trust-based relations, industrial atmosphere for growing human capital and entrepreneurship, collective pro-



1. Ecosystem Map of the textile district, with the proposition of the Recycling Hub as platform manager.
All images are reproduced in color in the online edition of the book.

cesses of creativity) (Becattini, 2004). Despite facing challenges related to environmental sustainability, these clusters have managed issues like waste and water management through collective investments (Bellandi et al., 2021). Prato, for example, has a long-standing tradition of wool recycling, which has become a foundation for Circular Business Models (CBMs).

CBMs focus on reducing energy consumption and waste, integrating strategies like reuse, recycling, and product longevity. In the textile industry, three types of CBMs—"more use per user," "more users per product," and "beyond the physical product"—have been identified (Ellen MacArthur Foundation, 2021). However, CBMs face difficulties in competing with the dominant linear, growth-oriented models, such as fast fashion, which offer cheaper short-term solutions, like exporting waste (Buchel et al., 2022). SMEs, though well-positioned to drive CBM innovation due to their sensitivity to social and environmental contexts, often struggle with limited resources for innovation and coordination. Effective CBMs require cooperation along value chains where SMEs might compete. Platforms and districts play a crucial role in providing services that help SMEs explore ecodesign and navigate coordinated CBMs. Districts, such as Prato, function as open laboratories where SMEs can adapt to the cultural, technological, and organizational changes needed to embrace CBMs (Bellandi & Storai, 2022).

The following sections will discuss the development of a cross-sector platform for traceability and circularity services for textile SMEs, highlighting the opportunities and challenges faced by platforms and district-based SME clusters.

4. From the concept to the prototype

The Desk and Field research identified four key areas of focus:

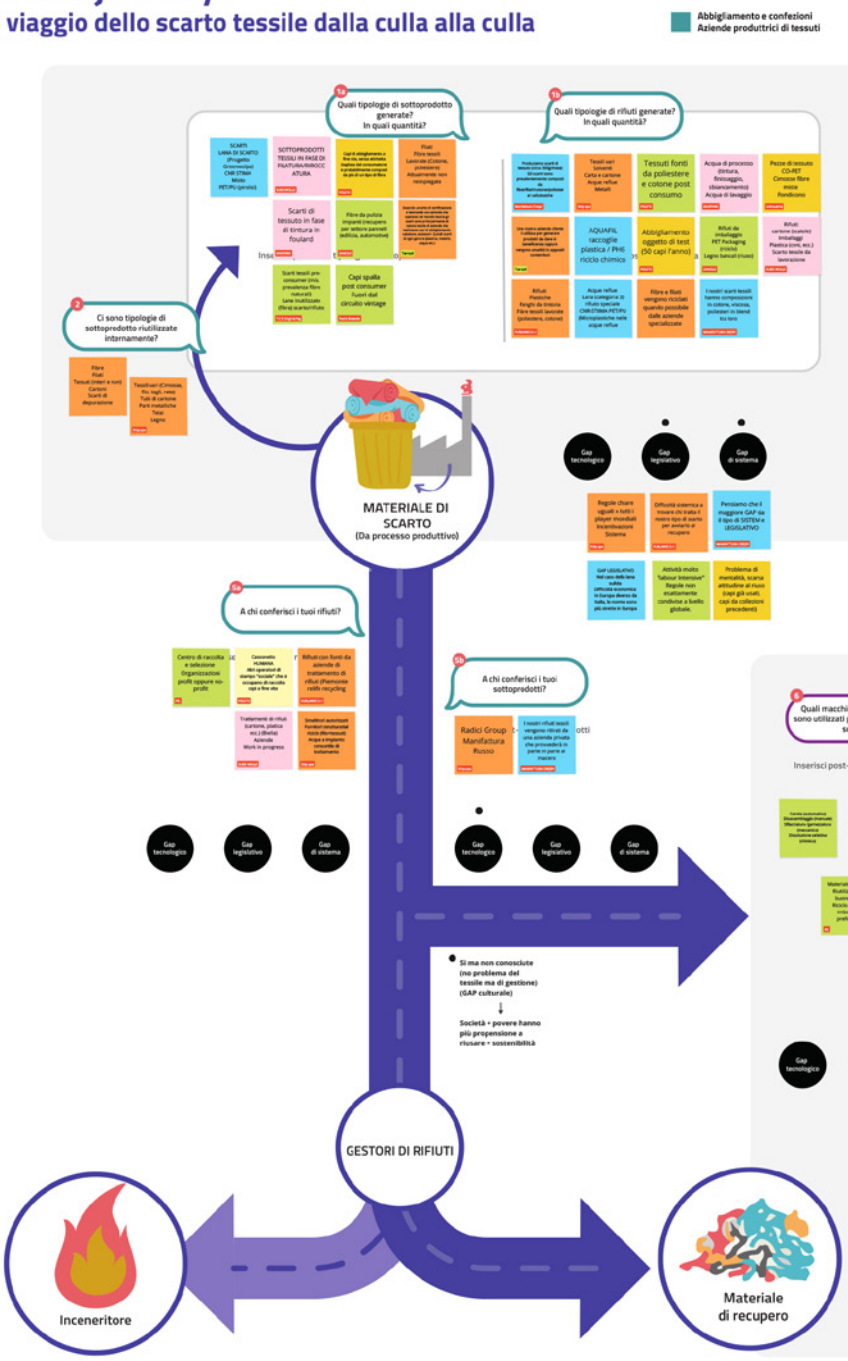
- Law & Regulations: lack of clarity exists in regulations concerning textile waste, recovery of exported materials, and reuse of recycled products in other sectors, hindering their certification and market competitiveness;
- Circular Network: absence of local waste supply chains to reduce dependence on secondary raw materials from

abroad, along with inadequate solutions for processing and valorising textile waste;
- Circular Products & Materials: The cross-sectoral application of recycled materials is limited by a lack of awareness of their potential and regulatory barriers, affecting market competitiveness. However, transforming waste into a resource could unlock new competitive market opportunities;
- Technologies and Digital Platforms: The implementation of tracking systems for pre- and post-consumer products is necessary to ensure transparency and compliance with European regulations. Potential integration of AI, LCA, and tracking systems is also explored.

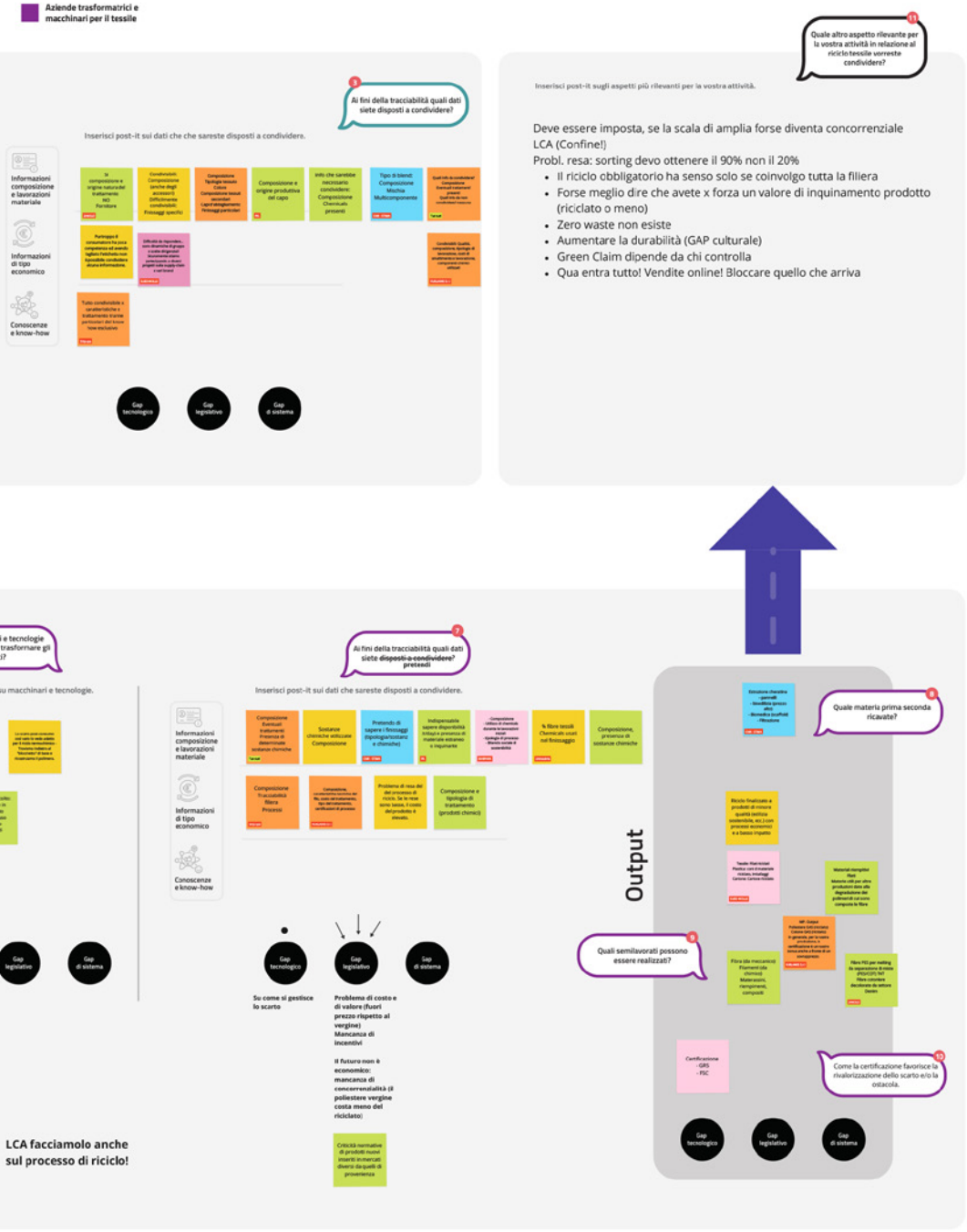
The research then focused on designing a range of services to address these identified gaps and offered by web-platform. Moreover to validate the platform's service offerings, a co-design process was conducted with stakeholders from the Prato District and Biella District (fig. 2). This process included the use of card games to encourage dialogue around proposed solutions. The initiative was informed by data from field research (literature review and best practices) and desk analysis (stakeholder analysis and recycling scenarios). The co-design approach was structured to engage stakeholders in defining long-term goals and identifying conditions necessary to achieve them, aiding in the planning and evaluation of project ideas. Key opportunities for the platform were identified in two areas: the creation of a database to connect companies via cross-sector case studies, and the development of tools for SMEs to collect technical data for improving traceability and ecodesign of pre- and post-consumer textiles. These traceability requirements for semi-finished and recycled textiles are aligned with Digital Product Passport legislation and analysis of online databases.

4.1. Designing the "Cross-sectoral Platform"

The proposed strategy adopts an integrated approach, connecting textile companies with those in other sectors to drive local cross-sectoral development. This fosters a circular and sustainable approach that addresses waste while creating growth opportunities for Made in Italy companies through innovation, diversification, and local resource enhancement. The service



2. Tool and output from the co-design activity related to the second phase of the research project.


Aziende trasformatrici e macchinari per il tessile
Ai fini della tracciabilità quali dati siete disposti a condividere?
Inserisci post-it sui dati che che sareste disposti a condividere.
Informazioni composizione e lavorazioni materiale
Informazioni di tipo economico
Conoscenze e know-how
Gap tecnologico
Gap legislativo
Gap di sistema
Quale altro aspetto rilevante per la vostra attività in relazione al riciclo tessile vorreste condividere?
Inserisci post-it sugli aspetti più rilevanti per la vostra attività.
Deve essere imposta, se la scala di amplia forse diventa concorrenziale
LCA (Confine!)
Probl. resa: sorting devo ottenere il 90% non il 20%
• Il riciclo obbligatorio ha senso solo se coinvolgo tutta la filiera
• Forse meglio dire che avete x forza un valore di inquinamento prodotto (riciclato o meno)
• Zero waste non esiste
• Aumentare la durabilità (GAP culturale)
• Green Claim dipende da chi controlla
• Qua entra tutto! Vendite online! Bloccare quello che arriva
Output
Quale materia prima seconda ricavate?
Quali semilavorati possono essere realizzati?
Come la certificazione favorisce la rivalorizzazione dello scarto e/o la ostacola.
Su come si gestisce lo scarto
Problema di costo e di valore (fuori prezzo rispetto ai vergine)
Mancanza di incentivi
Il futuro non è economico:
mancanza di concorrenzialità (il poliestere vergine costa meno del riciclato)
Criticità normative di prodotti nuovi inseriti in mercati diversi da quelli di provenienza
LCA facciamolo anche sul processo di riciclo!

platform envisions a world where companies access sustainability expertise and collaborate to promote sustainable development. The platform's mission is to support the transition to circular and cross-sectoral business models, promoting ecodesign through the reuse of textile waste. It aims to drive global change by creating local synergies and fostering collaboration among stakeholders.

The platform is then designed for collaboration, allowing users to share content based on their role in the ecosystem, which can evolve with market opportunities (fig. 3). The platform is organised into three sections:

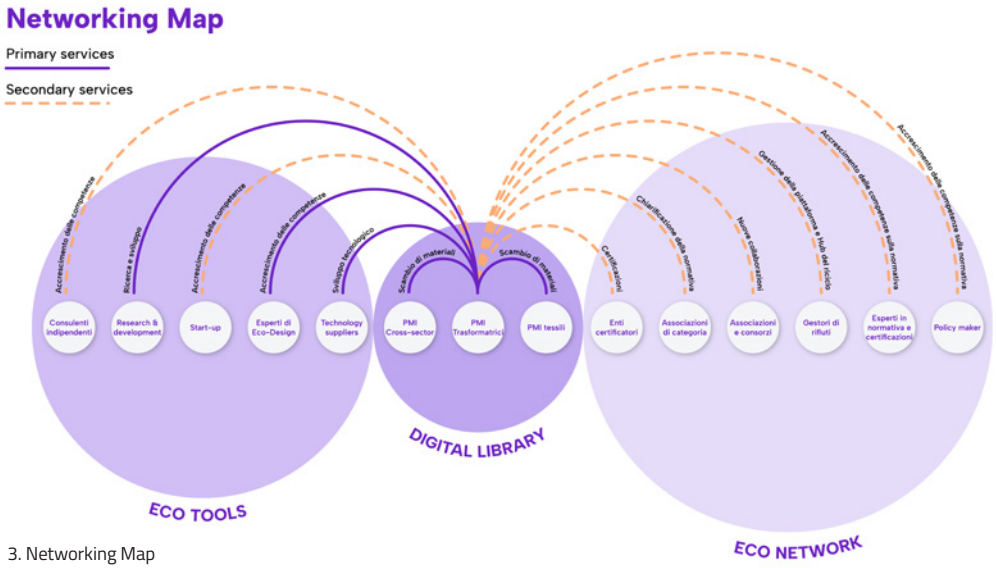
- Digitalibrary: The core section, facilitating the cross-sectoral reuse of pre-consumer textile waste through a secure traceability system (Digital Waste Passport) and a certified marketplace;
- Eco-toolkit: Provides SMEs with access to ecodesign tools, calculation software (e.g., LCA), best practices, and consulting services on sustainability and regulations;
- Eco-network: Enhances sectoral and cross-sectoral networking through features like social walls, challenges, and interactive infographics to increase engagement.

From the State-of-Art on the four topics discussed above, it was possible to proceed with mapping of the platform stakeholders, as well as organizing them by areas of platform interaction within the textile supply chain. Finally a Stakeholders Map was organized into Primary, Secondary and Indirect stakeholders.

Those stakeholders were analyzed and arranged into an Ecosystem Map (fig. 2), through the lens of the product end-of-life cycle. Finally, three layers were highlighted in the Ecosystem of the Prato Textile District: a **"core business"** layer, an **"extended enterprises"** layer and a **"wider business"** layer.

The ecosystem map built on the three layers sets a clear overview of the stakeholders already involved in the textile value-chain and offers a wider overview of the opportunities of involvement.

User research, including interviews, surveys, and site visits, explored the technological and circular capabilities of 224 companies, identifying service needs in areas such as LCA, ecode-



3. Networking Map of the Cross-sectorial Platform. The map shows the interactions between the users and three platform sections: Digital Waste Library, Eco-tool, Eco Networking.

sign, traceability, waste treatment, and digitalization. Co-design sessions engaged potential stakeholders to address specific challenges. The target users of the platform include textile and fashion SMEs, waste management firms, recycling technology producers, sustainability experts, and trade associations.

Then six archetype users (personas) were developed, including a wool-yarn producer, garment manufacturer, textile waste processor, start-up, sustainability consultant, and association president. These personas helped define the platform's architecture and usability, considering each user's digitalization level, sustainability awareness, frustrations, and needs, and aligning them with platform solutions.

4.2. Digital Waste Passport Prototype

Through the partnership in the MICS project of Italtel spa, it has been possible to go forward the design phase and start the prototype of the cross-sectoral Platform. The Digital Waste Passport (DWP) was selected as the prototype's foundation, serving as the core functionality of the web platform and a key competitive advantage.

The DWP generates verified information regarding waste materials through blockchain technology, enabling users to of-

fer second-life opportunities for textile waste while providing a secure marketplace for others to acquire pre-consumer secondary raw materials. This functionality is essential for facilitating the circularity of textiles within sectoral and cross-sectoral contexts.

In response to the current absence of a Digital Product Passport, the DWP was constructed based on the sustainability data required in various contexts, focusing on information pertinent to Life Cycle Assessment (LCA), ecolabels, and supply chain traceability and transparency. These data were organized through a blockchain technology to ensure a validity of data and generate a safe and controlled market.

Ongoing actions aim to preliminarily define the Digital Product Passport by mapping the requirements necessary for developing tools that meet stakeholder interests. This will follow the realisation of a mock-up and the validation with preselected stakeholders.

With the purpose to achieve a preliminary definition of DPP, a set of actions are ongoing. Actions are oriented to provide a first mapping of the requirements necessary to define an architecture that satisfies the development of tools of interest to stakeholders, not yet defined, following the completion of the state-of-the-art document. Prerequisites: Study of tasks defined by the proponent to determine the role and activities under Italtel expertise.

5. Conclusion

The proposed intervention aims to address the critical need for sustainable solutions within an uncertain and evolving regulatory framework. This uncertainty complicates the authorization processes necessary for cross-sectoral collaboration and the reuse of secondary raw materials. Key barriers include high investment costs, long payback periods, and regulatory uncertainties.

The introduction of the Digital Product Passport (DPP) in the textile sector promises transformation but is currently slow and fragmented, lacking a unified framework. While DPP schemes exist in other sectors, their impact on textiles remains

uncertain, and it is unclear whether a single or multiple passports will be established for products.

The research here presented, and its web platform output aims to fill the gap between regulation goals and companies capabilities. The Digital Waste Passport designed from this research aims to show one of the workable solutions to facilitate the End-of-life process and finally achieve circularity in the textile supply chain. Moreover, new collaborative services are needed to help SMEs join the circular supply chain and ecodesign opportunities. To facilitate this transition, the design of service platform would be crucial for SMEs and industrial designers, providing clarity on traceability regulations and promoting the reuse of pre-consumer waste as a resource. Strengthening local capacities and fostering collaboration between public and private entities will enhance the textile production chain through a cross-sectoral approach, contributing to economic growth and sustainability.

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