Fecha de recepción: febrero 2025
Fecha de aprobación: abril 2025

# Smart packaging as an enhancer of sustainability in the fashion Industry: Transitioning to new circular practices in the Made in Italy Supply Chain

Erik Ciravegna [(1)], Ludovica Rosato [(2)], Mariapaola Puglielli [(3)] and Martina Spinelli [(4)]

**Abstract:** The fashion system is characterized by pre-production, production, distribution, use, and disposal processes with significant and negative environmental and human impacts. The entire supply chain accounts for 3 to 10% of global emissions and consumes substantial amounts of water, land, and resources, actively contributing to climate change. Moreover, the fast fashion production model promotes decentralized production, intensifying impacts related to transportation, packaging, and distribution processes, positioning the fashion supply chain as a systemic, large-scale issue that requires a sustainable and circular transition.

The Advanced Design Unit (ADU) research group at the University of Bologna believes that this transformation can be driven by the *Transitional Industrial Designer*, a designer capable of incorporating mediation and anticipation practices to foster a sustainable and circular transition of industrial processes, integrating Transition Design practices with Advanced Design and disciplines emerging from Design for Sustainability.

This article aims to present an experiment focusing on new circular practices for the distribution phase of the fashion supply chain. The study is conducted within the framework of the project *FuturE-Pack*: *Digital Advanced Design for the Enhancement of Packaging as a 'Broadcaster' in the Made in Italy Supply Chain*.

Digital technologies are revolutionizing the role of packaging, transforming it from a mere container into an intelligent device capable of tracking products, monitoring safety, and ensuring quality. Packaging now serves as an enhanced communication tool, conveying brand values and engaging consumers.

This article outlines the objectives and methods of an experiment conducted with companies from the IT and fashion sectors to explore how packaging can act as an enhancer of information exchange for the sustainability and circularity of fashion products, promoting responsible production and consumption and advancing the sector toward a circular economy.

**Keywords:** Transition Design - Advanced Design - Fashion Supply Chain - Smart Packaging - E-Commerce - Circular Design - Design for Sustainability - Made in Italy - Digital Technologies - Systemic Approach

[Resúmenes en inglés y portugués en las páginas 226-227]

(1) **Erik Ciravegna**, Department of Architecture, Alma Mater Studiorum–Università di Bologna. PhD in Design from Politecnico di Milano. Currently, he is a Researcher and Lecturer at the Advanced Design Unit (ADU) in the Department of Architecture of the University of Bologna. He is also a visiting professor at the Pontifical Catholic University of Chile. His work has a background in communication design, with a focus on packaging design, product identity and branding. He has a strong interest in the ethics and social responsibility of the project and the role of design in promoting sustainable and circular practices. He is also dedicated to developing methods and tools at the intersection of art and design to support people's creative well-being and project innovation. erik.ciravegna@unibo.it

(2) **Ludovica Rosato** Department of Architecture, Alma Mater Studiorum–Università di Bologna. PhD in Design and Master's in Advanced Product Design at the University of Bologna, where he is currently a Research Fellow and Lecturer, member of the Advanced Design Unit (ADU) of the Department of Architecture. She obtained her PhD in 2023 with a thesis on the role of the designer in the sustainable and circular polymer transition, with an experiment in the textile sector. Among her research activities, she is currently collaborating on the development of a cross-sectoral platform for sustainable and circular textiles for Made in Italy, as part of the funded project PNRR PE11 *MICS-Made in Italy Circolare e Sostenibile* (Circular and Sustainable Made in Italy). ludovica.rosato2@unibo.it

(3) **Mariapaola Puglielli** Department of Architecture and Design, Politecnico di Torino. PhD researcher in "Design and Technology: People, Environment, Systems" at Politecnico di Torino. With a background in Industrial and Environmental Design from the University of Camerino and a Master's in Systemic Design from Politecnico di Torino, she is a dedicated member of the Sys-Systemic Design Lab research team. Her research focuses on fostering sustainable transitions within Made in Italy supply chains, emphasizing circular economy principles and the Systemic Design approach.
Her PhD activities are part of the PE11 partnership Made in Italy Circolare e Sostenibile (MICS), funded by Next Generation EU under the National Recovery and Resilience Plan (PNRR). mariapaola.puglielli@polito.it

(4) **Martina Spinelli** Department of Management and Production Engineering, Politecnico di Torino. PhD Candidate at the Dipartimento di Ingegneria Gestionale e della Produzione at Politecnico di Torino and member of the Sys-Systemic Design Lab research team. Her research explores the dynamics and relationships within circular ecosystems. She holds a Master's degree in Eco-Social Design from the Libera Università di Bolzano. The PhD activities are part of the Nodes, North West Digital and Sustainable under the National Recovery and Resilience Plan (PNRR). martina.spinelli@polito.it

## 1. Introduction

This article aims to present the initial results of the project *FuturE-Pack. Digital Advanced Design for the Enhancement of Packaging as a 'Broadcaster' in the Made in Italy Supply Chain,* a part of the research activities of the MICS extended partnership (PNRR PE11), involving researchers from University of Bologna, University of Florence and Polytechnic University of Turin. *FuturE-Pack* explores the application of digital solutions to enhance packaging as a communication device for the exchange of relevant information within Made in Italy sectors. The project aims to develop a portfolio of digitally advanced solutions to enhance the role of packaging as both a mediator and a communication channel ("broadcaster") within the supply chain.
By enhancing traceability, recording impacts, and ensuring product safety and quality, the goal is twofold: on the one hand, to enrich the end-user experience and encourage more informed purchasing and consumption choices; on the other, to facilitate the exchange of information among supply chain actors, fostering greater collaboration and accountability. This also enables clearer communication of territorial identity and the value of Made in Italy products.
As an expected outcome, the project aims to develop an interactive digital platform to support companies and designers in creating smart packaging solutions, with the goal of enhancing supply chain circularity, consumer engagement, and brand communication. This platform will provide a design toolkit, including guidelines, checklists, and best practices, enabling the development of innovative and sustainable packaging.
The digital interactive system will include *(See Figure 1):*

**1.** A taxonomy of digital systems for advanced packaging, with a range of technologies to meet diverse needs and requirements;
**2.** A catalog of impact assessment methods and tools to assess the environmental (LCA), social (S-LCA), and economic (LCC) impact of packaged products;
**3.** Various background materials, including a glossary of key terms, a collection of relevant laws and regulations, and a bibliography for study and training purposes;
**4.** A toolkit for advanced design of digitally enhanced packaging solutions, customizable to the specific needs of each company or industrial designer, with guidelines, checklists, and best practices that enable the creation of communicative, functional, and sustainable packaging solutions.

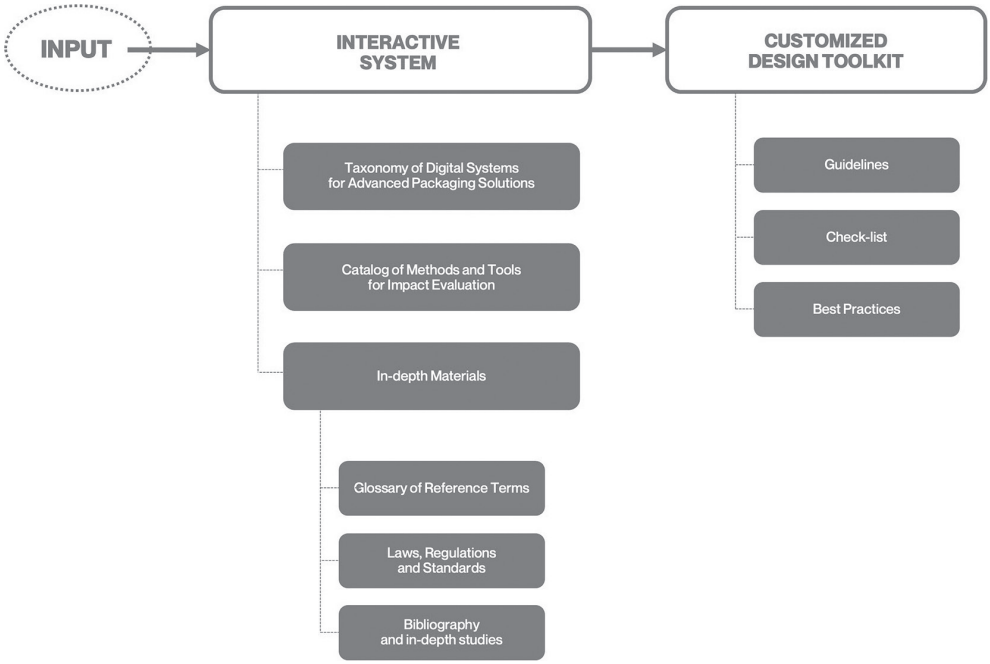



**Figure 1.** Expected Outcome: A Platform to Support Digitally Enhanced Advanced Packaging Design.

To support the design and development process of the platform, an experimental phase has been initiated in collaboration with partners from the IT and fashion sectors to develop smart packaging prototypes for e-commerce applications. The article focuses particularly on this experiment, which is now in its initial phase. Finally, a Smart Packaging Observatory is planned as an extension of the platform.

The contribution, building upon the contribution presented in the previous issue of the journal (Ciravegna *et al.*, 2024), is structured as follows: following a brief introduction to the project, it presents the problematic context and then the desk and field research conducted, which has been instrumental in gaining insights and key references on the project context; it then outlines the phases completed and those planned for the ongoing practical experimentation and it concludes with a discussion on the project's future prospects.

## 2. A Context in Need of Innovation: E-commerce Packaging in the Fashion Supply Chain

Thanks to digital innovations, packaging has evolved into a true '*smart device*'.Technological advancements have significantly expanded its capabilities as a powerful and complex communication tool (Ciravegna, 2010; 2017), it now not only conveys product characteristics and brand values but also tracks the production chain, ensures product integrity and safety, and records the entire lifecycle of each item, including its environmental and social impacts.

Beyond its functional role, packaging serves as a crucial mediator, strategically connecting supply chain actors and bridging the gap between businesses and end consumers. This role has become even more pivotal with the rise of e-commerce, which has driven profound changes in the sector and sparked essential discussions on sustainability. The urgency of these considerations has been further amplified by increasingly stringent regulations on packaging waste, such as the so-called PPWR (European Commission, 2022).

The Ecodesign for Sustainable Products Regulation (ESPR), published on March 30, 2022 (European Commission, 2022), stands out as one of the central measures within the policy package aimed at realizing the objectives of the 2020 Circular Economy Action Plan (European Commission, 2020). The regulation is designed to support the transition towards a circular, sustainable, and competitive economic model, enabling the EU to meet its environmental and climate targets, increase the circularity rate of materials used, and achieve energy efficiency goals by 2030. To accomplish these objectives, the ESPR introduces ecodesign regulations for various categories of critical products, proposing strategies that delay the recycling phase as much as possible. It promotes key principles such as durability, reusability, upgradability, and repairability, the reduction of substances harmful to circularity, resource efficiency, the use of recycled materials, remanufacturing, and the reduction of carbon and environmental footprints. Additionally, it establishes mandatory information requirements, such as the Digital Product Passport (DPP), which gathers data on the environmental sustainability of products throughout their lifecycle. This tool helps consumers and businesses make more informed choices while also simplifying verification and compliance processes for regulatory authorities.

These top-down regulations clearly demonstrate that utilizing smart packaging to convey information on circularity and sustainability through digital devices can serve as a highly relevant and strategic design approach.

In the fashion supply chain, e-commerce has become an increasingly prevalent purchasing method, further exacerbating the challenges of a system that spans production, distribution, use, and disposal, generating negative impacts on both the environment and people (Vezzoli *et al.*, 2022).

The continuous consumer demand for new garments—worn on average only 7–10 times before being discarded (Ellen MacArthur Foundation, 2021)—results in the production of approximately 15 kg of textile waste per capita per year in Europe, 85% of which originates from post-consumer textiles (McKinsey & Company, 2022: 13).

However, the environmental impact of the supply chain is not limited to textile waste; distribution also plays a significant role, particularly due to transportation, packaging,

and the storage and sales activities carried out by suppliers. The environmental impact of transportation varies depending on the distance traveled and the mode of transport used, while that of packaging is determined by the waste generated from primary, secondary, and tertiary packaging. Overall, this phase contributes to the depletion of fossil resources, climate change, human toxicity due to air pollution, and winter smog (Vezzoli *et al.*, 2022). In Italy, the impact of logistics within the Made in Italy system for fashion and furniture is often mitigated by district-based policies, which favor the proximity of sub-suppliers throughout the entire production chain. However, in the case of textile sourcing, such proximity is not always feasible, as textile production operates on an international scale (Textile Exchange, 2022), affecting the logistics of the entire supply chain and the final product.
The integration of smart packaging solutions, which not only comply with sustainability and circularity guidelines but also communicate key information to users, makes the complexity of the supply chain more transparent. This, in turn, raises consumer awareness of the environmental impact of their purchases and enables them to distinguish between circular and non-circular products.

## 3. Smart Packaging Solutions for E-commerce: An In-Depth Desk and Field Study

In this challenging context, the research conducted thus far to achieve the expected results has, first of all, focused on mapping and analyzing the state of the art.
From a methodological point of view, the state of the art was constructed based on these activities:

**A.**- literature review on packaging design, digital systems, sustainability, and circularity, Made in Italy, the fashion industry, and e-commerce;
**B.**- collection, cataloging, and analysis of case studies referring to existing digital systems already applied or potentially applicable to packaging and/or fashion products, with a focus on the functionalities they enable and the purposes they serve;
**C.**- mapping the supply chain and ecosystem of players in the fashion industry, intertwined with the e-commerce sales channel and the use of packaging within it;
**D.**- analysis of fashion products, their materials, characteristics, and requirements;
**E.**- analysis of triple impacts of package goods (LCA/S-LCA/LCC) and collection of methods and tools for the assessment of the life cycle of products;
**F.**- collection of methods and tools for assessment and design from other domains and for purposes other than those of the project;
**G.**- definition of a glossary of relevant terms related to the project themes;
**H.**- research on laws and regulations at the national and European level related to the project themes.

The literature review (**A**) was oriented toward the theoretical deepening of the topic of smart packaging and the categorization of advanced digital solutions, already applied or

potentially applicable to logistics, packaging, and delivery. Also, it examined the main functions of smart packaging, their different applications, and other relevant aspects; moreover, this investigation revealed the diverse purposes for which digital systems are currently being applied, including, by way of example, optimizing logistics, transportation, and storage; facilitating re-commerce operations; facilitating use, reuse, and end-of-life management through easier instructions; communicating clearer and more complete information on the impact of products; tracking and tracing of goods.

The process of collecting, cataloging, and analyzing case studies (**B**) has led to the identification of 230 entries, systematically archived within an online database using the Airtable platform (https://airtable.com). This database facilitates efficient data consultation, enables the establishment of interlinked relationships for cross-analysis, and supports the generation of synthesized visual representations for individual or grouped variables. These features enhance the comprehension of the current state of the field and provide valuable insights for future project developments.

The systematized online database, which includes case studies on advanced digital systems as well as relevant packaging solutions for the fashion industry, the e-commerce sector, and the B2B market segment, serves as the foundation for a comprehensive observatory dedicated to the project's core themes *(See Figure 2).*

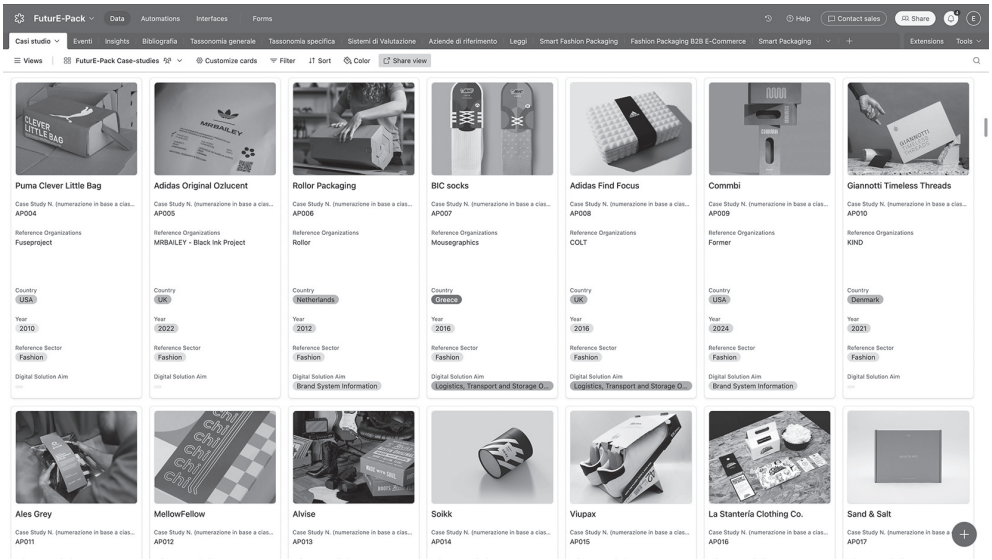



**Figure 2.** State-of-the-Art. Mapping and Analysis: Construction of a Systematized Database.

The in-depth study and systematization of case studies led to the definition of an expanded taxonomy of digital technologies applicable to packaging design *(See Figure 3)*, with a range of solutions that can meet the different needs and requirements that may manifest products, supply chain actors, and end users.
The taxonomy, which is currently under revision to achieve greater precision in the terminology employed to describe the various technologies encompassed, is structured into four primary categories, each of which is further organized into subcategories, as detailed below.

- Data Carrier: Digital Watermarks, Barcodes, QR Codes, RFID (Radio-Frequency Identification) Tags, NFC (Near Field Communication) Tags, AR (Augmented Reality) Codes, Web AR Codes, VR (Virtual Reality) Codes.
- Indicators: Gas/Gas Leakage Indicators, Freshness Indicators, Temperature Indicators (TTIs), Integrity Indicators, Electronic/Conductive Inks.
- Sensors: Biosensors, Chemical Sensors, Movement Sensors, Humidity Sensors, Temperature Sensors/Thermochromic Inks, Gas Sensors.
- Other Solutions: Bluetooth, GPS/Geolocation, IoT (Internet of Things), AI (Artificial Intelligence) / Machine Learning, Cloud Computing, Blockchain, Display, UHF (Ultra High Frequency).

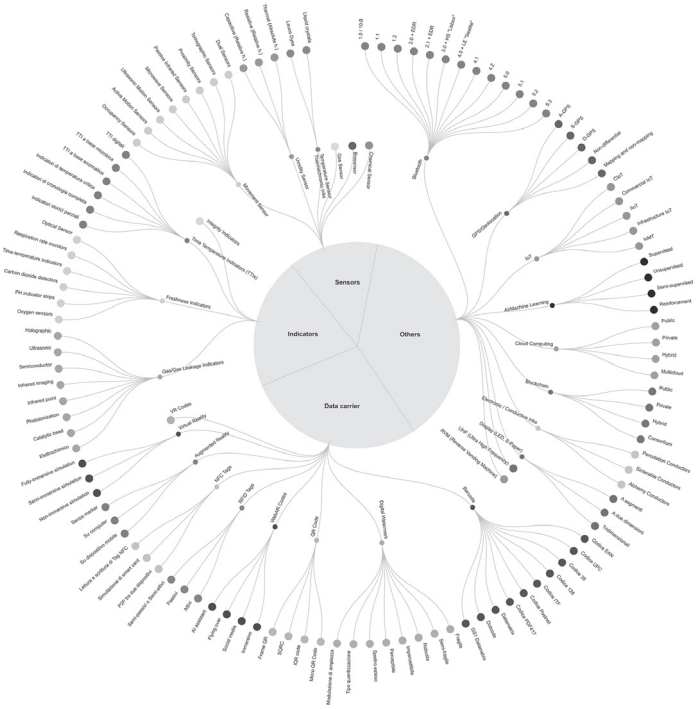



**Figure 3.**
Taxonomy of Digital Technologies Applicable to Packaging Design.

The study also encompassed a detailed mapping of the fashion industry's supply chain (**C**), examining the intricate ecosystem of stakeholders and their interconnections. This mapping exercise further explored the integration of e-commerce sales channels within the supply chain and the significant role of packaging in online retail operations. Furthermore, the research involved a comprehensive analysis of fashion products, delving into their diverse materials, distinct characteristics, and specific requirements. This analysis aimed to provide a deeper understanding of the complexities and nuances associated with fashion products across the supply chain.
The fashion e-commerce supply chain was represented by showing the intersections between the production flows and the actors involved in both the front-end of the user journey and the back-end business relations. The entire flow was divided into three main segments, as follows.

- From Production to Selling – B2B *(See Figures 4 and 5).*
- Selling Phases – B2C *(See Figure 6).*
- Consumption to Post-Consumption – C/C2C/C2B *(See Figures 7 and 8).*

This classification was essential in identifying the most suitable phase to be further explored during the experimentation process.

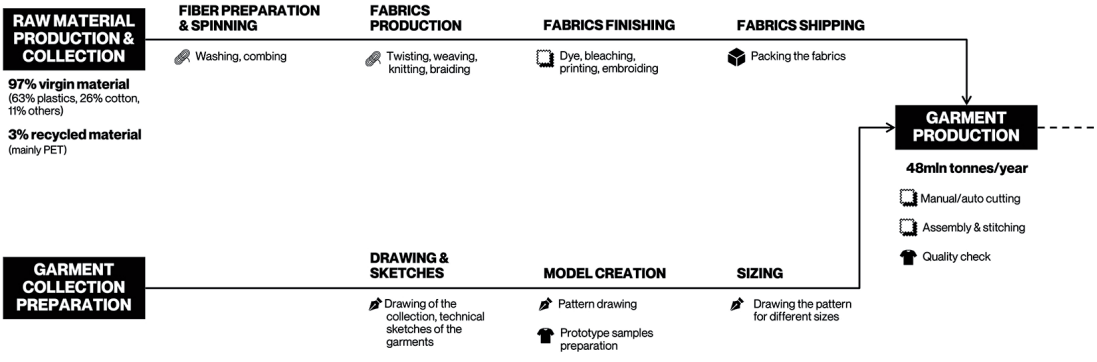
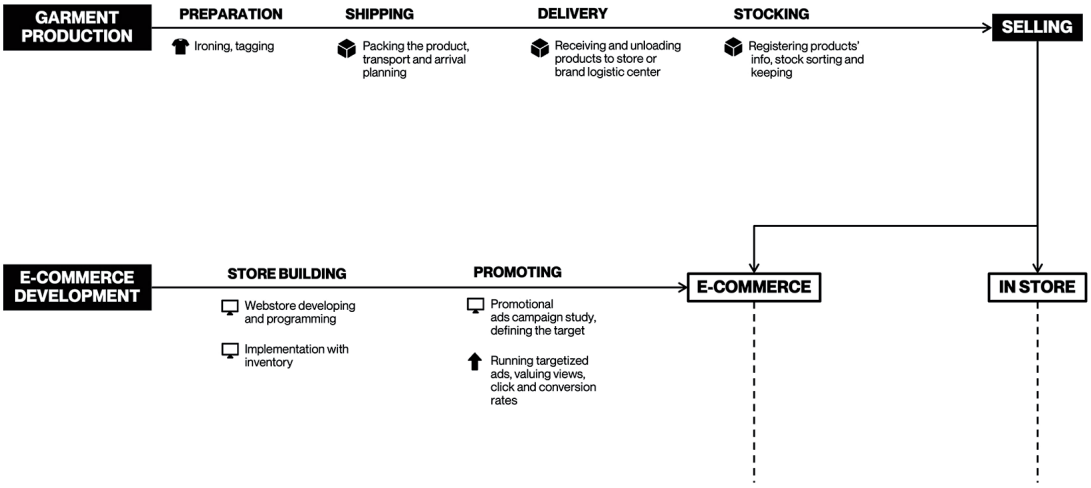
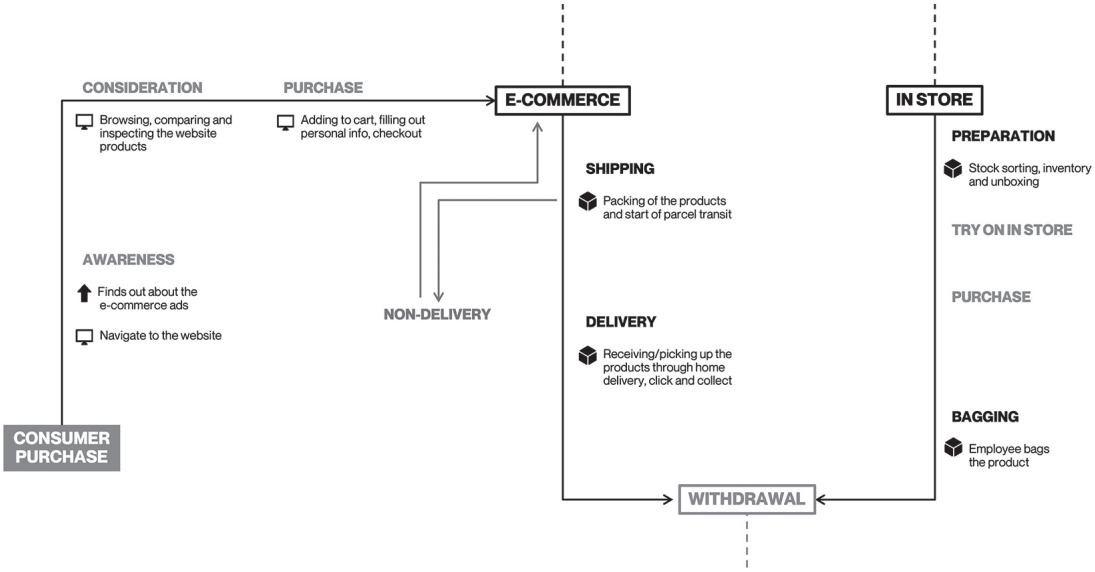



**Figure 4.** Mapping of the Fashion Industry's Supply Chain: From Production to Selling (B2B).

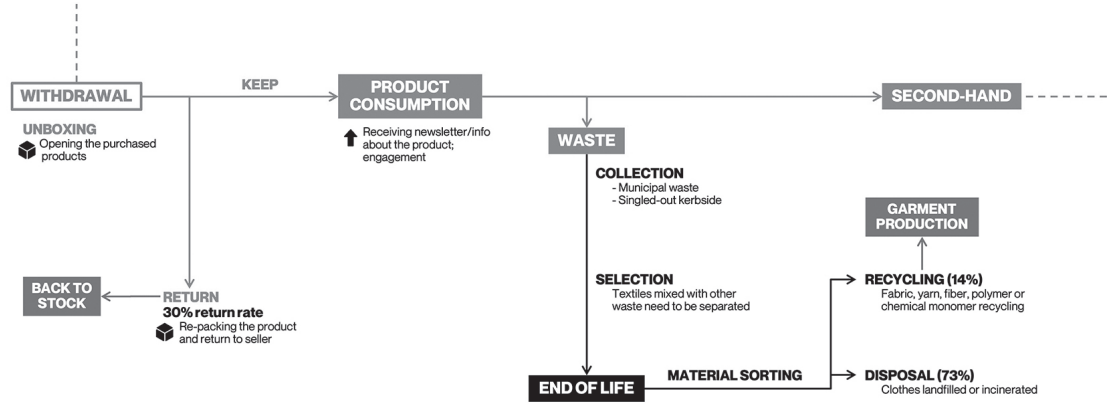



5

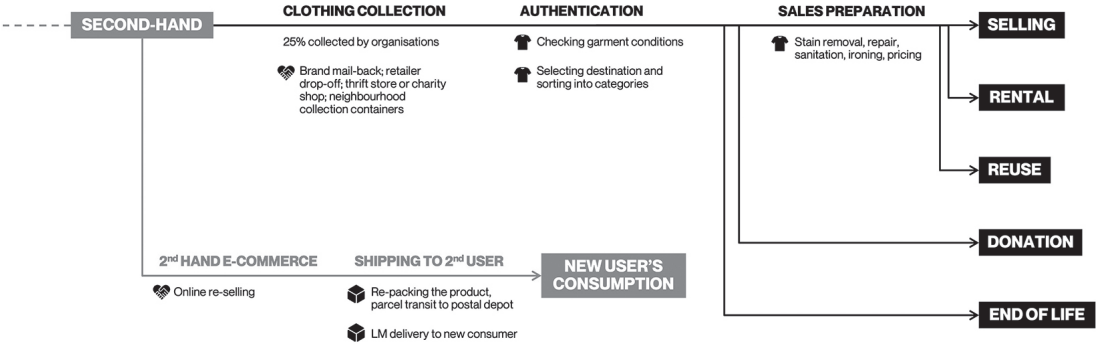



6

**Figure 5.** Mapping of the Fashion Industry's Supply Chain: From Production to Selling (B2B). **Figure 6.** Mapping of the Fashion Industry's Supply Chain: Selling Phases (B2C).




7




8

**Figure 7.** Mapping of the Fashion Industry's Supply Chain: Consumption to Post-Consumption (C/C2C/C2B).
**Figure 8.** Mapping of the Fashion Industry's Supply Chain: Consumption to Post-Consumption (C/C2C/C2B).

The research identified the diverse players in the fashion industry, including raw material suppliers, manufacturers, distributors, retailers, and consumers, analyzing their roles and interrelationships within the supply chain. The study also explored the specific challenges and opportunities associated with integrating e-commerce sales channels, considering factors such as logistics, inventory management, and customer service. The crucial role of packaging in e-commerce fashion retail was highlighted, emphasizing its protective function during transportation, its contribution to branding and customer experience, and its environmental impact.

Moreover, the research delved into the categorization of fashion products (**D**) and analyzed the properties and characteristics of the various materials used, examining their implications for production, packaging, transport and logistics, durability and sustainability *(See Figure 9).* Finally, it analyzed the specific requirements associated with the products, considering the main causes of damage and risk factors, quality standards, safety regulations, labeling guidelines, and ethical considerations *(See Table 1).*


**Figure 9.** Fashion Product Materials.

**Table 1**. Main causes of damage and risk factors for Fashion Product Materials.

| Main Causes of Material Damage | | | | |
|---|---|---|---|---|
| **Textile Fibers**<br>- Pets<br>- Mold and Degradation<br>- Stain<br>- Cuts | **Leathers**<br>- Defects in Row Hides<br>- Scratches and Abrasions<br>- Stain<br>- Color Alteration<br>- Mold and Degradation | **Furs**<br>- Stain<br>- Color Alteration<br>- Mold and Degradation | **Glasses for Lenses**<br>- Color Alteration<br>- Scratches and Abrasions | **Other Materials**<br>- Rust<br>- Scratches and Abrasions<br>- Polymer Crystallization |

*FuturE-Pack* gains further relevance considering the impending implementation of the EU's Ecodesign for Sustainable Products Regulation (ESPR) and its key instrument, the Digital Product Passport (DPP). The DPP will provide comprehensive information on the environmental sustainability of products, aiming to enhance traceability and transparency across the supply chain. Moreover, it will improve product data management and sharing, crucial for promoting sustainable use, extending product lifespans, and fostering a circular economy.

In this context, digitally enhanced solutions for packaging and product labeling can play a vital role in archiving and communicating pertinent data related to the DPP. By utilizing robust assessment methods such as Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), these solutions can extend the scope of information to encompass the social and economic dimensions of sustainability, in addition to the environmental aspect.

In this sense, by adopting such a holistic approach, *FuturE-Pack* aspires to culminate in a systemic and comprehensive Life Cycle Sustainability Assessment (LCSA) to provide a complete picture of product sustainability. With this aim, a review of the scientific literature concerning the life cycle assessment of products and their impacts has been conducted **(E)**, according to the three pillars of sustainability: environmental (*planet*), social (*people*), and economic (*profit*). Among its goals, the project seeks to advance the understanding and application of LCSA as an integrated methodology for triple bottom line assessment of products.

To achieve this goal, a literature review led to the development of a systematized conceptual framework for addressing sustainability issues. This framework outlines key aspects of conducting a sustainability assessment, starting from the four types of analysis: Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), Life Cycle Costing (LCC), and Life Cycle Sustainability Assessment (LCSA).

The specific sets of indicators used in the LCA, S-LCA, and LCC methods to measure impacts are detailed, as a comprehensive approach to sustainability assessment, considering both environmental, social, and economic dimensions.

In addition, key certifications, regulations, and standards that relate to sustainability assessment are provided.
Ultimately, the project aims to develop a suite of solutions, including guidelines, recommendations, and best practices, to enhance traceability and transparency within the Made in Italy supply chain.
To this end, the research also explored various methods and tools for conducting product life cycle assessments (LCA) and evaluating their environmental, social, and economic impacts, drawing on examples from different sectors (**F**). Moreover, examples of evaluation and design methods and tools from other fields and for purposes other than those of the project were collected and analyzed. In addition to software, examples of guidelines, checklists, manuals, archives, and comprehensive toolkits were considered, with either quantitative or qualitative approaches, in both physical and digital media, the latter being static as well as interactive.
A total of 112 case studies has been collected so far, however, this research work is still in progress, and the final number of cases may grow. The catalog system comprises two main parts. The first includes the collection of general information about the project for a complete overview. It includes a project description and additional resources for more in-depth information on the evaluation method or design tool. The second part examines the relationship between the analyzed case and the key topics of the project, providing a detailed description of the main features of the method or tool.
This comprehensive analysis explored the fashion industry's supply chain dynamics, e-commerce integration, and the multifaceted nature of fashion products to provide a holistic understanding of the industry. Through this in-depth examination, along with the mapping and state-of-the-art analysis already presented, this research identified key constraints and requirements, ultimately producing a framework to guide the development of packaging solutions for the Italian-made fashion industry and the e-commerce channel.

## 4. Experimental Phase: Method, Actors and Objectives

The research served as the functional foundation for identifying the design directions relevant to the subsequent experimentation phase.
The experimentation is in the start-up phase and, as a primary objective, aims to simulate the design process that will be the foundation of the digital interactive system. This will involve designing smart packaging solutions for specific fashion products, incorporating relevant technological solutions, and mapping the complete design and production flow. Following this, a critical analysis of the results will be conducted, revisiting the applied practices, in-depth case studies, employed taxonomy, and the materials, technologies, and processes utilized. This analysis will identify the key elements and challenges, enabling a more informed, systematic, and effective design process for building the interactive digital system. Proofs of Concept will be developed and tested in collaboration with an IT company specializing in the development of blockchain applications and digital technologies to ensure transparent and accountable processes with traceable data.

A collaboration with an Italian fashion company operating in both the B2B and B2C segments is also being initiated. This company provided the product that will serve as the content of the packaging to be designed. The chain of production, sale, and consumption of that product will be able to be mapped and tracked thanks to blockchain technology. Once the packaging requirements is identified, a packaging company is expected to be involved in the development and feasibility testing of the smart solution.

The experimentation will ultimately result in the design of a smart packaging solution and its impacts (both in terms of traceability and materials/processes) on one or more segments of the supply chain (B2B, B2C, C2C). The product selected by the fashion company will provide quantitative information related to its production and traceability chain and participate in the decision-making process for the design. With input from the packaging company and the IT company supporting the digital technology component, smart packaging will be created.

This complex system of relationships aims to simulate as realistically as possible the complexity of the current supply chain, making the result concrete and the subsequent analysis process meaningful.

The experimentation will unfold in five successive phases *(See Figure 10)*, involving the four collaboration partners (Project 1.1 Research Group, IT Company, Fashion Company, Packaging Company) differently at each step, with specific activity packages allocated to each or some steps of the experimentation.


**Figure 10.**
Experimentation phases.

The planned phases are as follows:

**1. Product requirements analysis and definition:** in this phase the Research Group studies the selected textile product, its supply chain, and packaging needs, defining initial technical requirements and constraints for experimentation. The Fashion Company supports this by providing detailed information on the product, its characteristics, and production logistics. The Packaging Company contributes by analyzing packaging and logistical constraints and assisting in defining technical requirements.
**2. Definition of testing criteria:** In this phase, the project partners collaborate to develop a shared project brief. The Fashion Company acts as a client, providing constraints and later offering feedback. The Research Group defines the technical and formal characteristics of the packaging, determines key information to be conveyed (e.g., brand identity, sustainability, circularity), and identifies advanced digital devices for data recording and transmission. The IT Company supports the process by analyzing certification requirements, preparing datasets for blockchain/DLT, and evaluating system integration. The Packaging Company verifies and defines packaging requirements, ensuring feasibility for integrating digital devices for information recording and transmission.
**3. Design and development of experimentation:** In this phase, the Research Group leads the process, designing packaging and digital device solutions, selecting those that best meet project objectives, and producing at least one prototype. The IT Company begins prototype development based on technical requirements. The Fashion Company and Packaging Company provide feedback, support solution evaluation, and assist in prototyping efforts.
**4. Testing and validation of the solution:** In this phase, the Research Group tests and iterates prototypes, engaging stakeholders for validation. The IT Company performs initial and final prototype testing, while the Fashion Company supports testing and stakeholder validation.
**5. Analysis of results:** the final phase evaluates project outcomes and defines scalability criteria for the FuturE-Pack platform. The Research Group reverse-engineers solutions to analyze design decisions, scalability, and replicability in Made in Italy sectors. The IT, Fashion, and Packaging Companies support this process by providing industry-specific feedback.

## 5. Design of E-commerce Packaging for Sustainable and Circular Overcoat: first phase

The first phase of the experimentation led to the identification of two Italian companies, both highly engaged in developing solutions for circularity and sustainability in different ways.
Astrakode is the IT company involved, specializing in blockchain, a technology that can play a pivotal role in fostering sustainable practices in resource management, product reuse, and recycling due to its ability to ensure traceability, data security, and efficient management of digital documentation. This increases transparency and accountability in flow monitoring,

contributing to optimized product lifecycle management. Moreover, blockchain enhances material visibility and traceability throughout the supply chain, reducing resource usage, countering counterfeiting, supporting informed consumer choices, and connecting primary and secondary markets to promote a more sustainable economic model.

The selected fashion company is ZEROBARRACENTO, a brand redefining industry values through sustainability, inclusivity, and seasonless design. Prioritizing durability and transparency over trends, it follows a circular approach, minimizing waste and emissions while ensuring high-quality Italian craftsmanship.

Founded by Camilla Carrara, a graduate of Politecnico di Milano and ESMOD Berlin, ZEROBARRACENTO has been recognized for its contributions to sustainable fashion, receiving awards such as the Recycling Design Preis and Creative Conscience Award.

Through continuous research and innovation, ZEROBARRACENTO focuses on responsible fashion, contributing to a more sustainable industry.

In fact, the brand uses certified materials from responsible suppliers and employs zero-waste techniques, including monofiber fabrics and the elimination of hard-to-recycle accessories.

Adopting a mono-cycle approach, which entails designing mono-material garments, is a fundamental practice within circular fashion (Circular Fashion, 2018). Implementing this approach requires designing products composed entirely of materials suitable for the same recycling cycle. This means that all finishing elements and additional components, such as buttons, thread, size and care labels, must correspond to the primary material of the garment and align with its recycling process. In doing so, the product is designed to re-enter either the biological or technical cycle, allowing it to either biodegrade or be recycled and regenerated into new resources for future use.

One of the challenges of designing within a mono-cycle framework is the potential compromise between aesthetics and the quality of different components. Surface treatments and chemical finishes may impact the recyclability and overall quality of the regenerated product. To ensure material circularity, mono-material textile design and alternative surface treatments, such as laser engraving and embroidery for embellishment and decoration, can be utilized. If multiple material qualities are required to achieve a specific function or aesthetic, a garment can be designed for disassembly, meaning its components are assembled in a way that allows them to be separated post-use and recycled individually.

These practices are further enhanced by the zero-waste techniques employed by the brand as an alternative to conventional cut-and-sew methods. In garment production, the cut-and-sew technique is widely used but leads to the generation of approximately 10 to 20% of pre-consumer textile waste, which consists of fabric remnants left over after cutting non-rectangular garment pieces from rectangular fabric rolls (Abernathy *et al*., 1999). This process contributes to an alarming 60 billion square meters of newly produced fabric being discarded into landfills or incinerated annually (Rissanen & McQuillan, 2016).

Zero-waste garment design directly addresses this issue by ensuring 100% fabric utilization through cutting techniques specifically developed to maximize material efficiency. Not only does this approach eliminate textile waste, but it also preserves the garment's full potential for future modifications or transformation into a completely new piece, thereby extending its lifecycle within a circular fashion framework.

In the initial phase, the two companies were engaged through exchange and discussion sessions to validate the planned involvement methods outlined in the previously described experimentation plan.
The product subject to experimentation was identified by the Fashion company. ZERO-BARRACENTO selected the extra-long *Luciana* overcoat as its flagship product, as it could provide extensive information regarding the production chain, including materials used, suppliers, applied processes, user responsibility in terms of sustainability, and usage practices.
The Luciana overcoat is crafted from 100% carded wool Bi Bye® by Manteco, a recycled and recyclable fabric, and lined with 100% cupro Bemberg™, a biodegradable and compostable material derived from cotton production waste.
The Bi Bye® wool is certified with an Environmental Product Declaration (EPD) and complies with the Global Recycle Standard (GRS), Responsible Wool Standard (RWS), Organic Content Standard (OCS), and European Flax certifications across its entire supply chain. It is produced through a low-impact mechanical recycling process, utilizing pre- and post-consumer wool waste without the need for additional dyes or chemicals.
Conversely, Bemberg™ cupro consists of regenerated fibers sourced from cotton linter. Its production follows a transparent and traceable process, optimizing water and energy use while ensuring the near-total recovery of waste materials. Recognized as a recycled material, Bemberg™ holds RCS (Recycled Claim Standard), Oeko-Tex Standard 100, and Ecomark certifications. Furthermore, both the dyeing and finishing stages of the cupro fabric meet the Oeko-Tex Standard 100 criteria.
As highlighted in the research, identifying the territorial impacts of products and the materials they are composed of is a fundamental practice.
These are circular materials, renewed and renewable resources, originating either from cultivated sources or from materials reintegrated into the production cycle, whether from homogeneous or diverse supply chains (Pellizzari & Genovesi, 2020). The two described material flows correspond to the technical and biological cycles of the circular economy (Ellen MacArthur Foundation, 2013).
The two materials suppliers, located in northern Italy *(See Figure 11),* contribute to shortening the production chain, thereby reducing the environmental impact of logistics. The model of a virtuous supply chain will subsequently be mapped using blockchain technology for enhanced traceability and transparency in the e-commerce packaging concept of the experimentation.

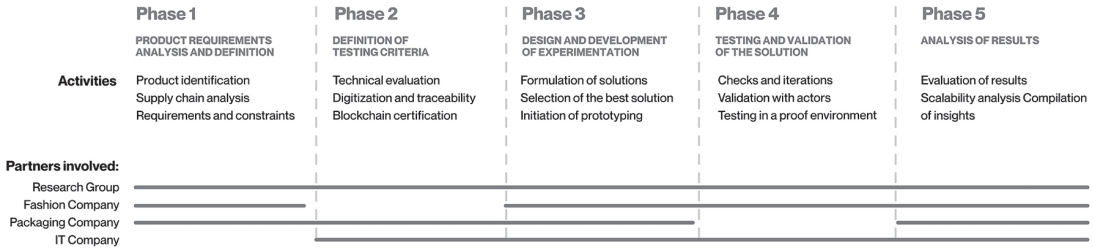



**Figure 11.** Material suppliers' supply chain Luciana Overcoat. Credits: ZEROBARRACENTO.

The Luciana overcoat is a minimalist and genderless garment, designed to be used by a broader audience over an extended period. It is less susceptible to fashion trends and changing consumer needs, thus promoting longevity and versatility.

This product stands in direct contrast to the aesthetic obsolescence imposed by the current fast-paced production and consumption system, typical of fast fashion. This system encourages users to constantly desire new garments while discarding old ones, under the illusion of acquiring unique products—when, in reality, they contribute to the globalized standardization of aesthetic taste (Jayot, 2020).

In designing our smart packaging solution, these aspects, related to the systemic sustainable and circular production of the garment, are fundamental. They represent the key information that must be communicated to users through packaging, ensuring awareness of the circularity and sustainability of the purchased product.

The specifications regarding the garment have been shared with the IT company, which will define the dataset required for the development of an information archive based on blockchain technology.

Simultaneously, the research team is working on defining the packaging and logistics requirements based on the product's characteristics.

Specifically, this process involves aligning functional and structural needs with communication requirements, while exploring potential packaging solutions and the corresponding data carriers that will enable smart e-commerce packaging. This phase is currently under development and requires close collaboration with ZEROBARRACENTO, which will define the necessary requirements from their perspective.

The initial phase of the experimentation highlights the fundamental importance of adopting a holistic and systemic approach in the design of smart e-commerce packaging for the fashion sector. A comprehensive analysis of the entire supply chain is essential not only to effectively communicate each sustainable and circular feature of the product but also to identify the most appropriate communication medium and packaging production method. The collaborative approach with the three companies, which will expand to four once the appropriate packaging solution meeting ZEROBARRACENTO's requirements is

identified, aims to establish a scalable and transparent model for sustainable fashion packaging, integrating circular principles with digital innovation to enhance product traceability and consumer awareness.

## Conclusions

This study explored the integration of smart packaging as a driver for sustainability and circularity within the fashion e-commerce supply chain, highlighting its potential to enhance traceability, improve consumer awareness, and reduce environmental impact.
Through a structured methodology —encompassing literature review, case study analysis, and experimentation— the research defined a framework for implementing digital technologies to transform packaging into an active communication and tracking tool.
This article presents the first phase of an ongoing experimentation aimed at developing smart packaging solutions for sustainable and circular e-commerce in the fashion industry. Through the collaboration between IT and fashion companies, the project has laid the groundwork for integrating blockchain technology with innovative packaging solutions to enhance traceability, transparency, and consumer awareness regarding the circularity of fashion products.
The FuturE-Pack project wants to demonstrate that smart packaging solutions can bridge the gap between sustainability goals and supply chain operations by incorporating advanced digital technologies such as blockchain, sensors, and data carriers. These solutions not only enhance the efficiency of logistics and distribution but also contribute to a more transparent and responsible consumption model.
Moving forward, the project will expand its validation efforts beyond fashion e-commerce to explore applications in the furniture sector, where packaging plays a crucial role in logistics and product protection. The scalability of smart packaging solutions will be further analyzed, with a focus on adaptability across different industries within the Made in Italy ecosystem.
Furthermore, the insights gained from experimentation will contribute to the development of the FuturE-Pack digital platform, a toolkit designed to support designers, brands, and supply chain actors in creating sustainable packaging solutions. By offering a structured approach to digital integration, the platform aims to facilitate the transition toward more circular and responsible distribution models, reinforcing the role of packaging as an enhancer of sustainability.
This first phase has demonstrated the potential of smart packaging as a key enabler of circularity, highlighting the strategic role of digital technologies in sustainable fashion distribution. Future developments will focus on scaling the experimentation, expanding partnerships, and further integrating smart packaging systems into the broader Made in Italy supply chain.

## Acknowledgements

*This study was carried out within the MICS (Made in Italy–Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR)–MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3–D.D. 1551.11-10-2022, PE00000004). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.*

## Bibliographical references

Abernathy, F. H., Dunlop, J., T., Hammond, J. H., & Weil, D. (1999). *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing - Lessons from the Apparel and Textile Industries.* Oxford University Press.

Ciravegna, E., Succini, L., & Rosato, L. (2024). Diseño avanzado para la circularidad y la sostenibilidad: soluciones digitales para apoyar la transición del Made in Italy. *Visiones del Diseño VII: Alfabetización ecológica y Transiciones sostenibles*, *222*, 279–290. https://doi.org/https://dx.doi.org/10.18682/cdc.vi222

Ciravegna, E. (2010). *La qualità del packaging*. FrancoAngeli.

Ciravegna, E. (2017). Diseño de packaging. Una aproximación sistémica a un artefacto complejo. *RChD: creación y pensamiento*, *2*(3), 1-17. https://doi.org/10.5354/0719-837X.2017.47825

Circular Fashion. (2018). *Circular Design Kit. Design strategies for material cyclability and longevity*.

Ellen MacArthur Foundation. (2021). *Circular design for fashion*. Ellen MacArthur Publishing.

Ellen MacArthur Foundation. (2013). *Towards the circular economy*. https://emf.thirdlight.com/link/x8ay372a3r11-k6775n/@/preview/1?o

European Commission. (2020). *Circular Economy Action Plan. For a cleaner and more competitive Europe*. https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

Jayot, E. (2020). A Designer Contribution to the Use of CNC Machines Within the Supply Chain in Order to Extend Clothing Life Span. In G. Vignali, L. F. Reid, D. Ryding, & C. E. Henninger (Eds.) *Technology-Driven Sustainability Innovation in the Fashion Supply Chain*. Pallgrave MacMillan.

McKinsey & Company. (2022). *Scaling textile recycling in Europe–turning waste into value*.

Pellizzari, A., & Genovesi, E. (2021). *Neo materiali 2.0 nell'economia circolare*. Edizioni Ambiente.

Rissanen, T., & McQuillan, H., (2016). *Zero Waste Fashion Design*. Bloomsbury, Fairchild Books.

Textile Exchange. (2022). *Preferred Fiber & Materials Market Report*.

Vezzoli, C., Conti, G. M., Macrì, L., & Motta, M. (2022). *Designing Sustainable Clothing Systems*. Franco Angeli. https://series.francoangeli.it/index.php/oa/catalog/view/804/649/4700

---

**Resumen:** El sistema de la moda se caracteriza por procesos de preproducción, producción, distribución, uso y eliminación con importantes e impactos negativos ambientales y humanos. Toda la cadena de suministro es responsable de entre el 3 y el 10% de las emisiones mundiales y consume cantidades sustanciales de agua, tierra y recursos, contribuyendo activamente al cambio climático.
Además, el modelo de producción de *moda rápida* promueve la producción descentralizada, intensificando los impactos relacionados con los procesos de transporte, embalaje y distribución, posicionando la cadena de suministro de la moda como un problema sistémico a gran escala que requiere una transición sostenible y circular.
El grupo de investigación *Advanced Design Unit* (ADU) de la Universidad de Bolonia cree que esta transformación puede ser impulsada por el *Diseñador Industrial de Transición*, un diseñador capaz de incorporar prácticas de mediación y anticipación para fomentar una transición sostenible y circular de los procesos industriales, integrando las prácticas del Diseño de Transición con el Diseño Avanzado y las disciplinas emergentes del Diseño para la Sostenibilidad.
Este artículo pretende presentar un experimento centrado en nuevas prácticas circulares para la fase de distribución de la cadena de suministro de la moda. El estudio se realiza en el marco del proyecto *FuturE-Pack: Digital Advanced Design for the Enhancement of Packaging as a 'Broadcaster' in the Made in Italy Supply Chain*.
Las tecnologías digitales están revolucionando el papel de los envases, que han dejado de ser meros contenedores para convertirse en dispositivos inteligentes capaces de rastrear los productos, controlar la seguridad y garantizar la calidad. El envase es ahora una herramienta de comunicación mejorada que transmite los valores de la marca y atrae a los consumidores.
Este artículo expone los objetivos y métodos de un experimento realizado con empresas de los sectores de la informática y la moda para explorar cómo el envase puede actuar como potenciador del intercambio de información para la sostenibilidad y circularidad de los productos de moda, promoviendo la producción y el consumo responsables y haciendo avanzar al sector hacia una economía circular.

**Palabras clave:** Diseño de transición - Diseño avanzado - Cadena de suministro de la moda - Embalaje inteligente - Comercio electrónico - Diseño circular - Diseño para la sostenibilidad - Made in Italy - Tecnologías digitales - Enfoque sistémico

**Resumo:** O sistema de moda é caracterizado por processos de pré-produção, produção, distribuição, uso e descarte com impactos ambientais e humanos significativos e negativos. Toda a cadeia de suprimentos é responsável por 3 a 10% das emissões globais e consome

quantidades substanciais de água, terra e recursos, contribuindo ativamente para a mudança climática.
Além disso, o modelo de produção fast fashion promove a produção descentralizada, intensificando os impactos relacionados aos processos de transporte, embalagem e distribuição, posicionando a cadeia de suprimentos da moda como um problema sistêmico e de grande escala que exige uma transição sustentável e circular.
O grupo de pesquisa da *Unidade de Design Avançado* (ADU) da Universidade de Bolonha acredita que essa transformação pode ser impulsionada pelo *Designer Industrial de Transição*, um designer capaz de incorporar práticas de mediação e antecipação para promover uma transição sustentável e circular dos processos industriais, integrando práticas de Design de Transição com Design Avançado e disciplinas emergentes do Design para Sustentabilidade.
Este artigo tem como objetivo apresentar um experimento com foco em novas práticas circulares para a fase de distribuição da cadeia de suprimentos de moda. O estudo é conduzido dentro da estrutura do projeto *FuturE-Pack: Digital Advanced Design for the Enhancement of Packaging as a 'Broadcaster' in the Made in Italy Supply Chain.*
As tecnologias digitais estão revolucionando o papel da embalagem, transformando-a de um mero recipiente em um dispositivo inteligente capaz de rastrear produtos, monitorar a segurança e garantir a qualidade. A embalagem agora serve como uma ferramenta de comunicação aprimorada, transmitindo os valores da marca e envolvendo os consumidores. Este artigo descreve os objetivos e os métodos de um experimento realizado com empresas dos setores de TI e moda para explorar como a embalagem pode atuar como um aprimorador da troca de informações para a sustentabilidade e a circularidade dos produtos de moda, promovendo a produção e o consumo responsáveis e avançando o setor em direção a uma economia circular.

**Palavras-chave:** Design de transição - Design avançado - Cadeia de suprimentos de moda - Embalagem inteligente - Comércio eletrônico - Design circular - Design para sustentabilidade - Made in Italy - Tecnologias digitais - Abordagem sistêmica