P/REFERENCES OF DESIGN

# UNLOCKING THE POTENTIAL OF POST-CONSUMER TEXTILE WASTE: EXPERIMENTING WITH NEW RECYCLING PRACTICES.

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**DOI: 10.63442/WUCH4901**

**KEYWORDS | TEXTILE WASTE, NEOMATERIAL, TEXTILE RECYCLING, MATERIALS DESIGN, PROCESS INNOVATION**

**ABSTRACT |** The textile sector represents one of the most important industrial supply chains in Italian manufacturing and, at the same time, is characterized by a significant ecological footprint.

In particular, end-of-life management of products is a significant challenge, both because of the textile composition composed of mixtures of synthetic and natural fibers - which hinders recycling operations - and because of the increasing volumes of material given the dynamics of fast fashion and changing production patterns. Currently, only 1 percent of textiles produced globally are reused, and the percentage of waste is expected to grow.

The increasing visibility of the problem has brought about a change in the perception of the fate of waste. The concept of waste today has taken on a positive connotation, being viewed no longer just as an inert object to be discarded but as a resource. Given the paradigm shift that sees waste as a new resource, it is crucial to outline a design framework that paves the way for a significant change of productive, economic, environmental, and cultural scope in the use of material resources. This approach becomes crucial to turn waste abundance into a design opportunity. The purpose of the research is to explore the potential applications of post-consumer textile waste, focusing mainly on textiles with mixed fiber composition and those whose material is difficult to identify due to the lack of labels, thus preventing the recycling process.

The objective is to study, test, and define a new process of producing neomaterials from post-consumer textile waste in mixed fibers and, from their qualitative and quantitative properties, define the most suitable application.

The research is supported by the main case study, Insieme Cooperativa Sociale of Vicenza. This entity (ex. L.381/91) is a non-profit organization (Onlus) that involves more than one hundred workers in a single project, giving a second chance to people and things that do not have one.

The research is structured into a desk research part and an applied research part. The former focuses on the analysis of the textile sector in the age of circularity, post-consumer waste management, and analysis of the relevant regulatory and economic framework. Important is the mapping of national and international case studies, which include all those entities operating in the textile waste and scrap recycling sector. The second phase focuses on the definition and application of the experimental methodology and is structured into the following phases: waste selection and sampling, material preparation and fraying, testing of material specimens, validation of the process, and analysis of qualitative and quantitative properties of the samples obtained.

The added value of the research will be precisely the promotion of new recovery actions that are struggling to emerge today, demonstrating the potentials of textile waste metamorphoses, intrinsic peculiarities, and otherwise little exploited properties. The research results can be used to devise targeted strategies to promote the application and dissemination of the developed process along with the related results obtained. This effort can help promote and increase the adoption of circular design and ecological transition principles within the area's manufacturing companies.

# 1. The Textile Industry in the Era of Circularity: from Production to Waste Management

The textile sector represents one of the most important industrial supply chains in Italian manufacturing and, at the same time, has a significant ecological footprint. The European Commission's Circular Economy Action Plan states that the textile sector is the fourth largest user of raw materials and water (after food, construction, and transport) and the fifth largest emitter of greenhouse gases, estimated to account for 10 percent of total global emissions (European Environment Agency [EEA], 2019). In addition, textile production has nearly doubled in the years between 2000 and 2015 (European Commission, 2020), and apparel consumption is estimated to grow 63 percent by 2030, from the current 62 million to 102 million tons (EEA, 2022). Many of these products, unsold in stores or worn only a few times, end up being thrown into illegal landfills, incinerated, or put into other routes (de Castro, 2021).
The problem extends to end-of-life management of products: the combination of increasing production and shortening the life cycle of garments has generated an exponential increase in textile waste. Currently, only 1 percent of globally produced textile materials are reused (Ellen MacArthur Foundation [EMF], 2017). The waste rate is set to grow: gross waste volumes are projected to increase to 8.5-9 million tons by 2030 due to increased consumption and population growth (Cobbing et al., 2022). In addition, due to some technological gaps, recycling operations are further complex for products composed of a mix of fibers.

# 2. From Vicious to Virtuous Circles: Waste as a Resource

These wastes constitute a fundamental and complex part of the life cycle of textile products and, at the same time, continue to be a pervasive element. The increasing visibility of the problem has brought about a change in the perception of their fate. The concept of waste has acquired a positive connotation, being considered no longer just as an inert object to get rid of but as a resource. This vision change allows the transition from a vicious circle to a virtuous one: waste and refuse from one production or consumption cycle become inputs for another process, different or similar to the previous one (Viale, 1994, p. 108). The outcome of this transformation is a rethinking of the cardinal positions of resources and waste as the starting and ending points of economic and production processes.
Consequently, it is essential to outline a design framework that paves the way for a significant change of productive, economic, environmental, and cultural significance in the use of material resources. This approach becomes crucial to turn waste abundance into a design opportunity to prevent a situation in which the waste issue can assume apocalyptic dimensions (Armiero, 2021).

# 3. Research Objectives and Methodology

Textiles today are the subject of great interest in recycling processes, motivated by significant environmental, social, and legislative pressures. In line with contemporary needs, the research aims to explore the potential applications of post-consumer textile waste, focusing mainly on textiles with mixed fiber composition and those whose material is challenging to identify due to the lack of labels, thus impeding the recycling process. The objective is to study, test, and define a new process of producing neomaterials from post-consumer textile waste in mixed fibers and, from their qualitative and quantitative attributes, determine the most suitable application.
The research is supported by the main case study, Insieme Cooperativa Sociale of Vicenza, a company that co-funded the doctoral fellowship. This entity (ex. L.381/91) is a Non-Profit Organization of Social Utility (Onlus) that involves more than one hundred workers in a single plan: to give a second chance to people and things that do not have one. Insieme Cooperativa Sociale collects, in the territory of Vicenza, 300 tons of textile inputs each year, specifically 100 tons per year of used garments collected in 18 municipalities and 200 tons of garments donated by citizens. Of this material, 65 percent manages to be recovered through reuse, recycling, or downcycling operations, while 35 percent becomes final waste. For Insieme

Cooperativa Sociale, it is essential to intervene in end-of-life waste management in such a way as to optimize all resources by implementing strategies aimed at maximizing the value of the material at each stage of its life cycle.
The research consists of two distinct parts: a desk research phase and another dedicated to applied research. The desk research focuses mainly on the investigation of the textile sector in the age of circularity, - assessing its environmental and socio-economic impacts - on post-consumer waste management, and the analysis of the relevant regulatory and economic framework. Of particular importance in this phase is the mapping of case studies at the national and international level, which include all those entities operating in the textile waste and scrap recycling sector.

The second phase, applied research, focuses on establishing the experimental methodology. The latter is framed in the following steps:

- **selection and sampling of waste**, starting with a big bag and sorted by (a) the presence or absence of the label and then (b) by prevailing material type;
- **preparation of the material and fraying**, the waste is stripped of non-textile components that could damage the machinery (buttons, zippers, various inserts) and subjected to a fraying reduction operation using the machine named "fraying machine";
- **experimentation of material specimens**, favoring treatments of a mechanical nature, to be replicated for each distinct group of frayed material and different reference batches;
- **validation of the process**, in the case of performing specimens, the process will have to be repeated to be validated;
- **analysis of qualitative and quantitative properties** of the material to define the most suitable application scenario.

# 4. Existing and Emerging Entities Engaging in Textile Waste Recycling

The reuse of textile scraps and waste has ancient roots: evidence of these practices dates back to the period between 1500 B.C. and 1500 A.D., where widespread recycling and reuse practices are traced not only for clothing but also for other purposes such as pots and pans, bricks, jewelry, insulation, etc. (Grömer, 2017). On the Italian territory, one of the most relevant examples is that of the textile district of Prato, which has been recycling wool from used clothes for more than 150 years - when these were called "rags" and recycling had no positive - meaning boasts numerous realities involved in studying, recycling or reusing textile material.
Today, these traditions are adapting to evolving textile composition, which is becoming more diverse, leading to innovations in recycling processes. This diversification has made it possible to identify three distinct approaches in recycling practices, influenced by the type of fiber input and output produced.
The analysis of the entities, divided into the three approaches, is intended to provide an overview of the promising emerging, productively diversified reality of companies or research groups that have reached different stages of development but are still relevant to the study.

## 4.1 Single Input Fibers that Remain Single

"Fiber-to-fiber" recycling processes are frequently marked by using mechanical practices. In conformity with ISO 5157:2023, such recycling processes are usually based on physical forces that can be used in isolation to recycle fabrics or fibers or as pre-processing for other recycling processes.
Manteco, a leading company in the Prato district, has launched MWool, a line of regenerated wool fabrics that meets the same stringent quality standards as virgin wool. Similarly, Beste, also in the Prato scene, is dedicated to regenerating natural fibers to reintegrate them into the fashion and related sectors. In Spain, Recover Fiber, based in Alicante, excels in processing cotton fibers from post-industrial and pre/post-consumer sources. The Recover™ recycling processes convert textile waste into high-quality recycled cotton fibers and blends, providing an end-to-end closed-loop solution.

## 4.2 Mixed Input Fibers that Return a Single

The case studies presented share an approach to chemical recycling, defined by ISO 5157:2023 as a process that uses chemical dissolution or chemical reactions to recycle polymers or monomers. A prime example is Renewcell, based in Sweden, which has introduced Circulose. Through the manipulation of clothing, Renewcell extracts cellulose dries it, and presses it into sheets, which are then processed into new textile fibers by third-party companies. Similarly, Infinite Fiber, based in Finland, has patented Infinna, a 100 percent material from post-consumer textiles, with at least 88 percent cotton, fully recycled and recyclable. The process of obtaining Infinna uses cellulose from fabrics, eliminating other matter, generating a virgin fiber that is similar to cotton and completely biodegradable.

## 4.3 Mixed Input Fibers that Remain Mixed

The case studies presented here address the complex challenge of recycling mixed fibers composed of post-consumer natural and synthetic materials. In these situations, the output does not belong in the textile sector because of the inferior material quality but finds innovative applications in other sectors. A significant example is Paris-based FabBrick, which uses patented technology to transform textile waste into semi-finished or finished products using a natural resin. In Campi Bisenzio, near Firenze, Manifattura Maiano converts textile scraps and industrial waste into thermoacoustic panels, which are then sanitized without water, chemicals, or adhesives. If the product is free of contamination, it can be fully recovered for recycling or reuse. In Ebeltoft, Denmark, Kvadrat stands out for processing post-consumer wool and cotton into panels and felt used as vertical wall coverings or as tabletops (Textile Tabletop). The felts, composed mainly of industrial wool waste and thermoplastic binder, are produced without the use of any artificial dyes or chemicals, exhibiting variations in color and fiber arrangement from batch to batch.

Table 1. Classification of case studies by type of fiber input, type of waste, output, and recycling.

| Case study | Classification | Type of waste | Type of recycling | Website |
|---|---|---|---|---|
| Manteco (Italy) | Single input fiber that return single | Post-industrial, post-consumer | Mechanical | manteco.com |
| Beste (Italy) | Single input fiber that return single | Post-industrial, pre-consumer | Mechanical | beste.it |
| Recover Fiber (Spain) | Single input fiber that return single | Post-industrial, pre-consumer, post-consumer | Mechanical | recoverfiber.com |
| Renewcell (Sweden) | Mixed input fiber that return single | Post-industrial, post-consumer | Chemical | circulo.se/en/ |
| Infinited Fiber (Finland) | Mixed input fiber that return single | Post-consumer | Mechanical, chemical | infinitedfiber.com |
| FabBrick (France) | Mixed input fiber that remain mixed | Pre-consumer, post-consumer | Experimental | fab-brick.com |
| Manifattura Maiano (Italy) | Mixed input fibers that remained mixed | Post-industrial, post-consumer | Mechanical | maiano.it |
| Kvadrat (Denmark) | Mixed input fibers that remained fibers | Post-industrial, post-consumer | Experimental | kvadrat.dk |

# 5. Initial Results, Next Step, and Conclusion

Although virtuous examples emerge of realities operating in the sector, recycling - which starts from an upstream rethinking since separate collections - especially for post-consumer, remains a segment of the textile value chain to be built almost from scratch (Berardi et al., 2023). From the analysis of the case studies, three different approaches in textile recycling practices were intercepted, which change according to the type of fiber inputs and outputs obtained, namely:

- Output composed of **single fiber inputs that remain single**, e.g., a material consisting of a single fiber, which is processed, often mechanically, to become mono-fiber yarn again;
- Output made up of **mixed input fibers that return single**, e.g., a material composed of polyester/cotton, which is processed, often chemically, to achieve monomer or polymer dissolution;
- Output composed of **mixed input fibers that remain mixed**, e.g., materials consisting of a fiber mix, often of unknown origin, that is processed mechanically to obtain semi-finished products composed of the same original fiber mix.

The initial analysis shows that recycling materials composed of a mixture of fibers is still an unresolved challenge. However, this is attributable to the lack of advanced technologies on the market and the tendency to process only specific types of fibers, even when present in blends. In an attempt to provide an answer to the problem, the applied research part has started.
Specifically, the first phase included the sorting and sampling of waste from an initial starting lot. These wastes were divided, at first, between labeled and unlabeled garments, and these wastes, at a later stage, were divided by prevailing fiber type, i.e., into (i) mixed fiber textile material with wool percentage >60%; (ii) mixed fiber textile material with synthetic fiber percentage >60%; (iii) mixed fiber textile material with cotton percentage >60%. The unlabeled textile material was not included in one of the described categories because the type of fibers could not be understood, but it will also be processed in the next stages of experimentation. The second stage involved the removal of non-textile components from the garments, such as buttons, zippers, and various applications (which would damage the machinery). Next, the waste was frayed by groups, as per the subdivision described, using the fraying machine on Cooperativa's premises. Once all the necessary frayed material has been obtained, the next step will be the production of neomaterial samples, using technologies and processes either specific to the textile sector or from other sectors. The goal is to draw inspiration also from entirely different contexts to address the problem at issue in an innovative way. The added value of the research will be precisely the promotion of new recovery actions that are struggling to emerge today, demonstrating the potentials of textile waste metamorphoses, intrinsic peculiarities, and otherwise little exploited properties. The research results can be used to develop targeted strategies to promote the application and dissemination of the developed process along with the related results obtained. This effort can help promote and increase the adoption of circular design and ecological transition principles within the area's manufacturing companies.

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**Acknowledgements:** the doctoral research is supported by Insieme Cooperativa Sociale of Vicenza, a co-financing company, as well as the main case study of the research.

# P/REFERENCES OF DESIGN

**This contribution was presented at Cumulus Budapest 2024: P/References of Design conference, hosted by the Moholy-Nagy University of Art and Design Budapest, Hungary between May 15-17, 2024.**

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ISBN Volume 1: 978-952-7549-02-5 (PDF)
ISBN Volume 2: 978-952-7549-03-2 (PDF)

DOI Volume 1: https://doi.org/10.63442/IZUP8898
DOI Volume 2: https://doi.org/10.63442/TADX4016

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