SITUATED TRACEABILITY IN POST-CONSUMER TEXTILE WASTE

INTEGRATING TECHNICAL DATA WITH THE BECOMING OF MATTER

CARMEN DIGIORGIO GIANNITTO
Università Iuav di Venezia/ Università degli Studi della Campania Luigi Vanvitelli, Caserta
cdigiorgiogiannitto@iuav.it;
Orcid 0000-0003-4817-0861

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.
Competing Interests: The Author(s) declare(s) no conflict of interest
DOI: 10.36253/fh-3638

Abstract

Circularity has become a crucial topic in the textile sector, highlighting the need to rethink production models still rooted in linear logics. In this context, post-consumer textile waste represents one of the most pressing challenges, as it consists of heterogeneous, contaminated materials that often lack a recognizable identity. To address these issues, the European Union has introduced the Digital Product Passport (DPP), a tool designed to ensure transparency across the entire product lifecycle. However, in cases of open-loop recycling — where materials are radically transformed and lose all connection to their origin — the linear model of traceability proposed by the DPP reveals its limitations. This article offers a critical reading of these limits and introduces the concept of situated traceability, capable of also valuing the inherent opacity of post-consumer materials. Starting from a reflection on experimental waste transformation practices and from theoretical approaches that interpret materials as dynamic and relational entities, the article proposes a vision of the DPP as a potential narrative interface. In this perspective, tracing does not only mean identifying technical data, but making visible the contexts, relationships, transformations, and meanings that intertwine around the material.

Keywords: *Situated traceability; Post-consumer textile waste; Digital Product Passport; Material opacity; Open-loop recycling*

REIMAGINING TRACEABILITY IN THE END-OF-LIFE PHASE OF TEXTILE PRODUCTS

In recent years, the discourse on circularity in the textile sector has taken center stage in political, academic, and design debates, in response to a production system still largely based on linear models, with significant environmental, social, and economic impacts (Hole & Hole, 2019). Within this context, post-consumer textile waste emerges as one of the key challenges in the transition toward truly circular models. It represents the largest waste stream in the European textile chain (European Environment Agency, 2024; Eppinger, 2022), consisting of garments discarded after use by the final consumer. These are often characterized by high heterogeneity, contamination, mixed fiber compositions, and low quality (Johnson et al., 2020; Wang, 2010). Such features make these materials difficult to sort and recycle through closed-loop systems (Huang et al., 2024). Nevertheless, it is estimated that most discarded textiles retain over 70% of their remaining useful life, revealing a systemic paradox that the industry struggles to recognize and address.

In response to this scenario, the European Union's proposal for the Ecodesign for Sustainable Products Regulation (ESPR) (European Commission, 2022a) outlines an ambitious framework to reform the textile supply chain toward circularity. The regulation promotes the adoption of ecodesign criteria, the use of recycled

and biocompatible materials, and the strengthening of practices such as repair, reuse, recycling, and industrial symbiosis. One of the key elements of this transition is the Digital Product Passport (DPP), a tool designed to ensure transparency along the entire value chain through a digital system that collects, stores, and provides access to standardized product information — from composition to manufacturing processes, usage guidelines to recycling options — accessible via a QR code or other digital identifier. However, where transparency becomes an imperative, the recycling of post-consumer materials reveals its opacity.

In cases of open-loop recycling — where materials are transformed into entirely different products, severing formal ties to their origin — the promises of the DPP risk collapsing under the impossibility of maintaining a linear, traceable genealogy. Although the DPP is also intended to support the retention of materials within closed-loop recycling systems, this goal is often constrained by technological and regulatory limitations. The closure of cycles cannot be infinite: with the progressive degradation of fibers, the loss of performance, or the contamination of materials, open-loop recycling becomes inevitable to avoid landfill or incineration. Several virtuous examples of open-loop textile recycling highlight how post-consumer waste can be reconfigured into neomaterials — a family of experimental, non-standardized materials newly defined and obtained from waste through processes that diverge from traditional recycling technologies, often as a result of regulatory constraints or technological limitations (Pellizzari & Genovesi, 2017). These practices are based on adaptive and non-linear approaches, in which material transformation does not rely on a single technology, but on processes using emerging techniques capable of responding to the heterogeneous nature of materials and generating new material identities.

What happens, then, when the origin is indecipherable, or when the material is the result of stratifications that are no longer distinguishable? This clash between normative ideals and operational reality generates a grey zone in which post-consumer textile waste emerges as a material "without origin," devoid of symbolic value and pushed to the margins of the official narrative of circularity. In response to this, the aim of this article is twofold: on the one hand, to explore the contradictions between the logic of total traceability and the complex, disorderly, and opaque reality of post-consumer recycling; on the other, to propose a reflection on the role of design in shaping forms of situated traceability that recognize opacity not necessarily as a system failure, but as an emergent quality. Specifically, the article suggests reimagining the Digital Product Passport (DPP) not merely as a repository of technical data, but as a potential narrative interface capable of conveying the transformability, trajectories, and relationships that characterize post-consumer textile waste as it takes on new forms and functions. In this perspective, recognizing opacity does not mean giving up on knowledge, but rather embracing the complexity of these materials in their processual and transformative dimension. The article is structured as follows. After framing the limits of linear traceability in the end-of-life phase of textile products, Section 2 critically examines the role and structural limitations of the Digital Product Passport (DPP) when applied to post-consumer textile waste and open-loop recycling. Section 3 articulates the concept of situated traceability through a theoretical dialogue with relational and material-driven approaches, addressing opacity as an emergent and generative condition of matter, and is supported by comparative diagrams illustrating the shift from linear to situated traceability models. Finally, Section 4 outlines the conclusions and discusses the implications of this framework for design practice and policy, proposing a pluralisation of traceability logics.

LIMITS OF LINEAR TRACEABILITY: THE DIGITAL PRODUCT PASSPORT AND POST-CONSUMER MATERIAL COMPLEXITIES

Traceability has become a key concept in the transition toward circularity in the textile sector. Understood as the ability to follow a product throughout its entire lifecycle — from raw material to end-of-life — it is promoted as a tool to ensure transparency, accountability, and to reduce the impact of our consumption. Within this framework, the Digital Product Passport (DPP) is positioned as a crucial informational infrastructure to enable a more circular textile sector, facilitating data sharing among producers, consumers, authorities, and third parties (European Commission, 2022b). The DPP is an integral part of the European Strategy for Sustainable Products and aims to make it mandatory to collect data related to composition,

durability, reparability, and environmental impact of textile products. This information should be linked to each item through an interoperable digital platform, accessible at every stage of its lifecycle (EEA, 2024).

The DPP is expected to provide all relevant stakeholders with accurate information about the features and performance of textile products, offering useful specifications on materials and substances used (ETP, 2024; European Commission, 2022b; Rugi, 2024). Expectations for this tool are high: greater visibility into material characteristics could enable improved eco-design, reuse, and recycling practices (Carvalho et al., 2025). However, the DPP is based on the assumption of a traceable supply chain from the very beginning — relying on new, homogeneous, and standardized materials — and it remains unclear how this tool might adapt to the structural specificities of materials at end-of-life. In particular, post-consumer textile waste represents one of the most critical challenges in the shift toward a truly circular economy.

The DPP is intended as a key tool to direct such materials toward the most suitable recovery channels, providing useful information to sorters, recyclers, and second-life operators. Yet, as materials move further away from their point of origin, traceability tends to weaken, especially in the presence of complex supply chains, physical damage, or subsequent transformations that alter the material's structure and readability (Legardeur & Ospital, 2024). Data entered during the early stages of the lifecycle — such as composition, production processes, and performance — do not necessarily reflect the product's actual condition at the end of use. While the DPP represents an important step toward informational transparency, it alone cannot ensure effective cycle closure: it must be embedded in a broader ecosystem that includes design practices, distribution models, and social frameworks capable of activating new meanings and uses for discarded materials. Moreover, even when post-consumer materials are formally accompanied by a Digital Product Passport (DPP), this does not guarantee their continuous recyclability within closed-loop systems. As fibres deteriorate, and undergo treatments, these materials progressively lose compatibility with homologous processes and are often diverted toward open-loop recycling paths. In this transition, any connection to the original identity dissolves, rendering the retrospective traceability envisioned by the DPP ineffective. Unlike closed-loop recycling, which aims to maintain coherence between input and output, open-loop recycling transforms materials into semi-finished products and goods with entirely different forms and uses (Abrishami et al., 2024; Heikkilä et al., 2024; Huang et al., 2024). Through this process, textiles become something else: acoustic insulation, technical padding, building components. The original product becomes unrecognizable — shredded, remixed, pressed, or agglomerated with binders — losing formal traceability and often the ability to distinguish fibre composition.

The outcome is a hybrid neomaterial, seemingly anonymous. In such cases, the gap between data and material widens: the transformed material loses any formal connection to the product it originated from, making it impossible to trace back to its source. Additionally, the handling of these materials often occurs through informal, decentralized, or local networks that elude standardized industrial digitization frameworks. The risk, then, is that the DPP ends up excluding precisely those materials that are most in need of being revalued — too opaque to be recognized by official systems. Digital information collected along the supply chain should be integrated with situated assessments of the material, regarding its current condition, remaining quality, and actual recyclability. Only through such integration can the DPP evolve from a static information repository into an operational tool that concretely supports recycling and end-of-life management. Within this scenario, it is necessary to explore alternative forms of traceability, not based on a certain origin, but on coherence of use, functional value, and the relational quality of materials (Fletcher & Tham, 2019.

TOWARDS SITUATED TRACEABILITY: TRANSPARENCY IN THE COMPLEXITY OF MATTER

The byproducts of our everyday lives, when no longer used or usable, are commonly referred to as "waste", a term that carries with it a sense of passivity and obsolescence, as if their value were exhausted with their original function. In French, *déchet* means "that which has fallen": something produced as a residue of constructing something else, destined to be hidden or eliminated (Paoletti, 2021). This notion of falling or invisibility echoes the challenges that post-consumer

infrastructures. Within the framework of the Digital Product Passport (DPP), transparency is promoted as an essential value. However, as Mattern (2017) argues, transparency is not a neutral concept: it is a technopolitical construct that defines what can be made visible and what remains excluded from knowledge systems. This observation becomes particularly relevant when addressing the issue of post-consumer materials, whose trajectories — marked by contamination, transformation, and repeated use cycles — often render them incompatible with the standards demanded by digital infrastructures. Rather than an anomaly, the opacity that emerges may be interpreted as a different kind of knowledge, one that challenges the linearity and stability upon which conventional traceability tools are built.

Tim Ingold (2007) contributes to expanding this perspective by proposing a view of materials not as static elements, but as entities in becoming, whose qualities emerge over time through relationships with the environment, tools, and people. The properties of materials, he argues, cannot be objectively determined or simply imagined; rather, they are practically experienced as the outcome of encounters and transformations. Each quality, in this sense, can be read as a condensed story, an expression of what happens to the material as it changes, blends, and deforms. To describe a material, for Ingold, is to narrate its lived experience, to trace a situated and open-ended genealogy made up of gestures, agents, and contexts. This approach encourages moving beyond fixed taxonomies and reading matter through its transformative trajectories (Ingold, 2007), aligning with an idea of traceability that is not linear but relational. This line of thought is echoed in the metaphor proposed by Ezio Manzini (1986), who suggests that describing a material is like trying to take a family photograph when all the members are moving. As Manzini points out, matter resists being fixed in a stable definition: it is mobile, relational, and its meaning takes shape over time through dynamic and layered processes. For both Ingold and Manzini, materials should be read as living phenomena, whose value does not lie in intrinsic properties, but in the transformative trajectories they undergo.

Following Karen Barad's (2007) perspective, the knowledge of materials is not objective or absolute, but emerges as an intra-active, relational, and situated process. Material truth is constructed through the interaction of things, contexts, and the transformative acts that involve them. In this view, designing within opacity means letting go of the ideal of total transparency and recognising opacity itself as a generative ground, where material qualities are not predefined, but continuously taking shape. Matter should not be understood as a set of fixed properties, but as the materialisation of phenomena, where each configuration results from evolving relations (Barad, 2007, p. 210). Materiality is therefore emergent, shaped by ongoing interactions, and materials do not have absolute ends, they undergo multiple transformations.

In line with Haraway's concept of situated knowledges, the object of knowledge must be understood as an actor and an agent, rather than as a passive resource to be represented (Haraway, 1988). Applied to post-consumer textile waste, this implies rethinking the Digital Product Passport not as a system that merely records information about inert materials, but as a device that interacts with active, transforming matter whose properties and meanings continuously evolve. Alternative forms of traceability exist that are not based on codes or databases, but emerge through sensory and transformative narratives of materials. In some cases, it is the textures, smells, density, or reaction to certain stimuli that tell the story of a material. In others, it is the gestures, tools, and local contexts that leave traces, generating forms of situated traceability. These forms of recognition do not necessarily reveal *where* a material comes from, but rather *how* it has been transformed, *by whom*, with which resources, and for what purposes. From this perspective, the Digital Product Passport (DPP) could be reimagined not as a mere technical archive, but as a narrative interface, one capable of conveying the complexity of material metamorphoses and the relationships that have made them possible. Rather than ensuring a closed and univocal genealogy, a reconfigured DPP could activate plural and localized narratives, supporting contextual interpretations and recognition practices that help guide the use and reuse of materials outside dominant industrial paradigms. This type of approach would be particularly relevant in contexts where post-consumer materials are recovered, transformed, or reconfigured in the absence of structured technical information, for instance, in local initiatives, circular micro-economies, or socially-driven design projects.

In this scenario, the principles proposed by the Earth Logic Plan (Fletcher & Tham, 2019) offer a valuable framework for rethinking the concept of traceability. While the dominant logic is grounded in linear, centralized models of data collection — oriented toward performance and control — the Earth Logic approach promotes a relational, situated, and plural vision. From this perspective, traceability is not merely the accumulation of technical information, but a construction of meaning over time and space: a participatory practice that emerges from places and is nurtured by relationships. Situated traceability thus becomes a form of knowledge embodied in processes, one that follows the material through its transformation, reflecting not only its origin but also its context. In this light, traceability could evolve from a tool of control into a practice of situated attention, attuned to the ways matter transforms and survives. Design practices, in this scenario, can play a decisive role in restoring meaning and value to textile waste materials, even when they fall

outside the normative parameters of traceability. The goal is not to reconstruct a lost origin, but to recognize the trajectory the material has undergone, what it has become, how it has acted, and what relationships it has activated along its path. These reflections suggest the possibility of reimagining the Digital Product Passport as more than a registry of technical and standardized data, integrating narrative, sensorial, and relational dimensions capable of conveying the transformability and situated trajectories of post-consumer materials. This approach does not strive for total knowledge, but rather acknowledges — as Barad emphasizes — that matter is constantly becoming, and that all traceability is always partial, situated, and contextual. A DPP conceived in this way could help enable new forms of circularity, not grounded in absolute transparency, but rooted in careful attention to what transforms, escapes, or is reinvented. The conceptual shift from linear to situated traceability is synthesized in (Figure 01) and (Figure 02), which compare the standard Digital Product Passport model with the proposed integration of situated micro-archives. To clarify the operational implications of situated traceability, one may consider the case of a batch of post-consumer garments initially documented through a standard Digital Product Passport. Once these materials enter an open-loop recycling process and are transformed into a new composite material for a different application, the original DPP data are no longer sufficient to describe the material metamorphosis. At this stage, a situated micro-archive can operate as a second level of traceability, documenting not only the identity of the original material, but the transformation process itself (Fig. 02), marking the passage from what the material was to what it has become. Such a micro-archive may record information related to the transformation — including the quantity of material processed, the type of process adopted, the site and the actors involved (for example social cooperatives or design-driven initiatives), the post-transformation composition (textile fraction, binders), as well as the main process parameters (mixing ratios, temperature, pressure, processing time). It may also collect the characteristics of the resulting neomaterial, both in terms of sensory properties (surface texture, rigidity, chromatic variations, odour release) and in terms of technical performances (response to humidity, sound absorption properties, mechanical behaviour, etc.). Finally, the micro-archive may include information concerning the output and the use scenarios activated — who uses the material, in which context, and through what type of exchange — as well as indications regarding possible future scenarios of reuse, repair, reprocessing, or further open-loop cycles. In this way, the micro-archive does not aim to preserve a linear genealogy of origin, but to sustain the continuity of material knowledge across transformations, enabling situated decision-making processes even when the identity of the original product is no longer fully retrievable. From a DPP perspective, this means that a passport informed by situated traceability would contain not only origin-based product data, but also process-based records of transformations, material

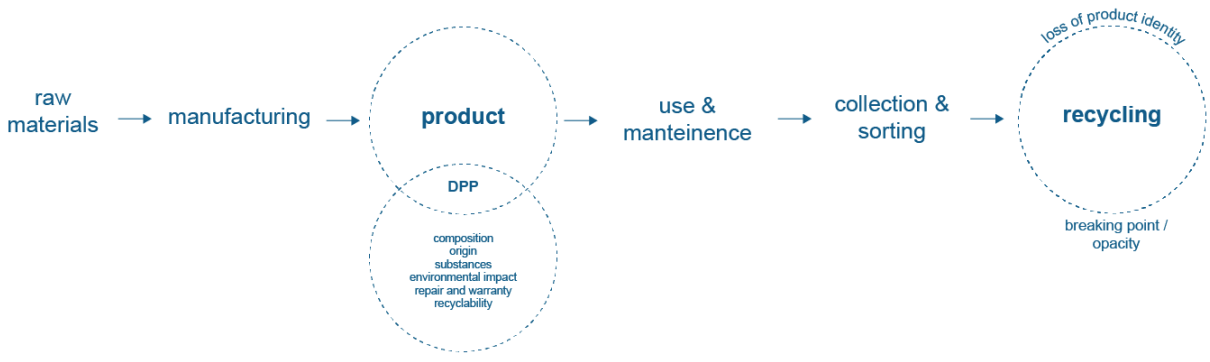

Fig. 01

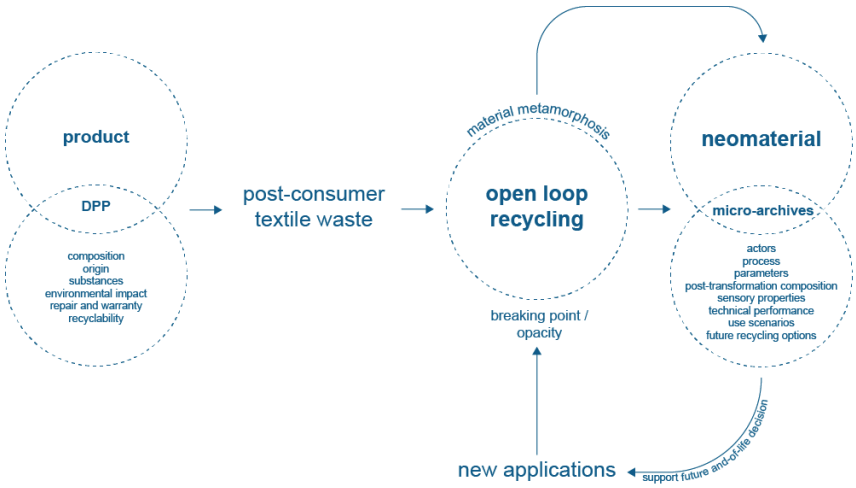

Fig. 02

performances, and use contexts, extending traceability beyond the first product life and following materials through successive open-loop transformations. Such practices of situated traceability would legitimise partial, local and experimental forms of documentation, also supported by digital tools, operating in dialogue with official infrastructures.

CONCLUSIONS: PLURALISING THE LOGICS OF TRACEABILITY

The reflection developed in this article aims to show how traceability, despite being one of the cornerstones of the circular transition envisioned by European policies, is neither a neutral nor an exhaustive process. The case of post-consumer textile waste emblematises the limits of a traceability system conceived through linear, codifying, and standardized logics. When materials lose their original form, pass through multiple cycles, or are combined with other substances, they escape digital codes and conventional taxonomies. Yet within this opacity, rather than an error to be corrected, one can recognize a different condition of understanding. As discussed, matter should not be considered a passive substrate but rather an active, relational entity capable of carrying stories, gestures, and contexts. Authors such as Mattern (2017), Ingold (2007), Manzini (1986), Barad (2007), and Fletcher & Tham (2019) invite us to rethink materiality as a process, a becoming, a transformative force. From this perspective, knowledge of textile products and materials does not coincide solely with the availability of objective, centralized data but emerges through situated and partial interactions that can activate new forms of understanding. In this framework, opacity is not the opposite of transparency, but its complementary condition: a space in which forms of situated knowledge can be activated.

From an epistemological perspective, in open-loop recycling processes — where materials are contaminated, mixed, and reconfigured — opacity does not simply signal a breakdown of traceability, but marks the transition toward other states, uses, and values of matter. In this sense, traceability can no longer be conceived solely as a backward-looking operation anchored to the identity of the previous product, but instead unfolds through transformations, following materials across successive states and uses. Within this framework, design is not understood as a neutral recorder of data, but as an epistemic mediator operating within material indeterminacy. By translating opacity into practices of situated documentation, micro-archives, and material narratives, design sustains the continuity of knowledge across cycles of transformation and enables informed decisions on future scenarios of reuse, repair, and further recycling. Following this line of thought, we propose an evolution of the

Digital Product Passport (DPP) capable of integrating qualitative, narrative, and relational dimensions. A DPP reframed through a situated lens could become a device that not only records technical data, but also incorporates material narratives, sensory cues, and local practices. This transformation calls for a revision of related policy frameworks: instead of focusing solely on maximizing data collection efficiency, it would be more appropriate to promote the coexistence of digital infrastructures and decentralized knowledge practices, rooted in contexts of production, transformation, reuse, and recycling. For example, the recognition of contextual forms of traceability could be supported through micro-archives, self-documentation tools, and open, accessible protocols, tools that could also valorize experimental materials, or neomaterials, such as those derived from open-loop recycling and non-standardized processes. In this transition, design can play a crucial role, not only as a technical enabler, but as an epistemic practice capable of mediating between the visible and the invisible, between systems and margins. Design practices can contribute to making such materials legible not through the imposition of labels, but by constructing interpretive frameworks, sensory experiences, and relational devices. In this sense, design becomes an agent of recognition, able to accompany materials into their second life without erasing their complexity. It is not about tracing back to the origin, but about building coherence of use, meaningful connections, and plural narratives. Finally, it is important to stress that situated traceability does not exclude digital traceability, it complements it, providing depth and context to what databases alone cannot register. In a time when environmental urgency demands that every material fragment be valued, even what falls, mixes, or transforms deserves attention. Only by acknowledging this plurality of logics — epistemic, material, and political — can we build a form of circularity that is not only technical, but also cultural and social.

CAPTIONS

[Fig. 01]Standard Digital Product Passport (DPP) model based on linear, origin-based traceability across the product lifecycle, from production to end of life. (Authors' Own Model).

[Fig. 02] Situated traceability model integrating a micro-archive within an open-loop recycling process, documenting material transformations, performances, actors, and use contexts beyond origin-based data. (Authors' Own Model).

REFERENCES

Abrishami, S., Shirali, A., Sharples, N., Kartal, G. E., Macintyre, L., & Doustdar, O. (2024). Textile recycling and recovery: An eco-friendly perspective on textile and garment industries challenges. *Textile Research Journal*, *94* (23–24), 2815–2834.

Barad, K. (2007). *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning*. Duke University Press.

Carvalho, C., Silva, C. J., & Abreu, M. J. (2025). Circular Economy: Literature Review on the Implementation of the Digital Product Passport (DPP) in the Textile Industry. *Sustainability*, *17*(5), 1802.

Eppinger, E. (2022). Recycling technologies for enabling sustainability transitions of the fashion industry: status quo and avenues for increasing post-consumer waste recycling. *Sustainability*, *18*(1), 114-128.

European Commission. (2022a). *Ecodesign for Sustainable Products Regulation*. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en

European Commission. (2022b). *Proposta di Regolamento Europeo e del Consiglio che stabilisce il quadro per l'elaborazione delle specifiche di progettazione ecocompatibile dei prodotti sostenibili e abroga la direttiva 2009/125/CE. COM (2022) 142 final*. https://eur-lex.europa.eu/legal-content/IT/TXT/HTML/?uri=CELEX:52022PC0142

European Environment Agency. (2024). *Management of used and waste textiles in Europe's circular economy*. https://www.eea.europa.eu/publications/management-of-used-and-waste-textiles

Fletcher, K., & Tham, M. (2019). *Earth logic: Fashion action research plan*. The J J Charitable Trust.

Haraway, D. (1988). Situated knowledges: The science question in feminism and the privilege of partial perspective. *Feminist Studies*, *14*(3), 575–599.

Heikkilä, P., Heikkilä, J., Kamppuri, T., Keskisaari, A., Määttänen, M., Saarimäki, E., Heikinheimo, L., Koivula, A., Rintala, N., & Harlin, A. (2024). *Technologies and Model for Sustainable Textile Recycling*. VTT Technical Research Centre of Finland. VTT Research Report Vol. VTT-R-00941-22.

Hole, G. & Hole, A.S. (2019). Recycling as the way to greener production: A mini review. *Journal of Cleaner Production*, *212*, 910-915.

Huang, X., Tan, Y., Huang, J., Zhu, G., Yin, R., Tao, X., & Tian, X. (2024). Industrialization of open-and closed-loop waste textiles recycling towards sustainability: A review. *Journal of Cleaner Production*, *436*, 140676.

Ingold, T. (2007). Materials against materiality. *Archaeological Dialogues*, *14*(1), 1–16.

Johnson, S., Echeverria, D., Venditti, R., Jameel, H., & Yao, Y. (2020). Supply chain of waste cotton recycling and reuse: A review. *AATCC Journal of Research*, *7*(1_suppl), 19-31.

Legardeur, J., & Ospital, P. (2024). *Digital product passport for the textile sector*. (Internship report for the European Parliament). HAL archive. https://hal.science/hal-04649885

Manzini, E. (1986). *La materia dell'invenzione*. Milano: Arcadia Edizioni.

Mattern, S. (2017). *Code and clay, data and dirt: Five thousand years of urban media*. University of Minnesota Press.

Paoletti, I. (2021). *Siate materialisti!*. Einaudi.

Pellizzari, A., & Genovesi, E. (2017). *Neomateriali nell'economia circolare*. Edizioni Ambiente.

Rugi, T. (2024, 13 maggio). *Passaporto digitale dei prodotti: i fattori di successo e le barriere secondo CircThread*. https://economiacircolare.com/passaporto-digitale-prodotti-circthread/

Wang, Y. (2010). Fiber and textile waste utilization. *Waste and biomass valorization*, *1*, 135-143.