



Circular Design Principles in Garment Construction: A Literature Review of Seams, Closures, and Disassembly Strategies for Textile Recycling

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Abstract

The global apparel industry generates textile waste at a rate that current recycling infrastructure cannot absorb, with well under a tenth of discarded clothing recovered into new textile products. A growing body of research identifies garment construction — specifically seams technology, closures and trims, and material-combination strategy — as a primary determinant of whether a garment can be mechanically or chemically recycled at end-of-life, independent of the fibres it is made from. This paper presents a narrative literature review synthesizing peer-reviewed and institutional research on circular design principles applied to garment seams, closures, and disassembly. Three constructs are examined: (1) Design for Disassembly (DfD) as a strategy for enabling material separation; (2) seam and stitch technologies, including thermally and microwave-triggered disassembly threads; and (3) closures and trims as recyclability bottlenecks. The review situates construction-level design choices within the broader circular economy literature and emerging European Union regulatory drivers, including the Ecodesign for Sustainable Products Regulation and textile Extended Producer Responsibility schemes. Findings indicate that mono-material construction, modular and detachable components, and engineered disassembly-triggered stitching show the greatest technical promise, but adoption remains constrained by production cost, absent standardization, and a persistent disconnect between design practice and recycling infrastructure capability. The paper concludes with a synthesis framework for construction-level circular design and identifies gaps warranting further empirical research, particularly the need to quantify disassembly-time and recycle-quality trade-offs across garment categories.

Keywords: circular economy; design for disassembly; garment construction; seam engineering; closures and trims; textile-to-textile recycling; sustainable fashion; extended producer responsibility.

1. Introduction

The global apparel industry operates on a predominantly linear model of resource extraction, production, use, and disposal. The Ellen MacArthur Foundation's landmark report estimated that 53 million tonnes of clothing are produced annually, with more than 97% of the fibre used consisting of virgin, largely non-renewable resources, and that more than 73% of discarded clothing is incinerated or landfilled, representing an estimated USD 100 billion in lost material value each year (Ellen MacArthur Foundation, 2017). Despite growing interest in recycling as a solution, the technical reality is that most textile recycling infrastructure remains immature: fibre-to-fibre recycling currently converts only a small fraction of post-consumer textile waste into new textile products, and mechanical recycling processes generally shorten and degrade fibre quality with each cycle, limiting genuinely closed-loop reuse (Stubbe et al., 2024).

A substantial body of circular economy (CE) scholarship treats textiles as one sector among several to which CE principles might be applied (Kirchherr et al., 2017; Lieder & Rashid, 2016). What is less consistently addressed in this literature is the extent to which recyclability is determined not primarily by fibre choice but by construction-level decisions made long before a garment reaches a recycler: how panels are joined, what threads and adhesives are used, how closures such as zips and buttons are attached, and whether components can be separated without destroying the base fabric. This is the domain of Design for Disassembly (DfD), a concept with roots in electronics and durable-goods design that has been adapted into a textile-specific research area only over roughly the last decade (Forst, 2020; Hall et al., 2023).

This paper undertakes a narrative literature review of circular design principles as they apply specifically to garment seams, closures, and disassembly-oriented construction. It intentionally narrows its focus to the construction and assembly stage of the garment lifecycle rather than treating the fashion circular economy as an undifferentiated whole. The paper poses three guiding questions:

RQ1: How do seam and stitch technologies affect a garment's technical recyclability at end-of-life?

RQ2: What role do closures and trims play as recyclability bottlenecks, and what construction-level alternatives have been proposed or implemented?

RQ3: How do current and emerging regulatory instruments create incentives, or disincentives, for disassembly-oriented garment construction?

The remainder of the paper is organized as follows. Section 2 outlines the review methodology. Section 3 develops a conceptual framework linking CE theory to DfD in textiles. Section 4 reviews the literature across six themes: seam construction, closures and trims, mono-material and modular strategies, recycling-technology interfaces, regulatory drivers, and barriers to adoption. Section 5 synthesizes the findings into an integrated framework. Section 6 discusses limitations, and Section 7 concludes with directions for future research.

2. Methodology

This paper adopts a narrative (non-systematic) literature review methodology, appropriate for synthesizing a still-emerging and interdisciplinary body of work spanning textile engineering, design research, and environmental policy. Sources were identified through targeted searches of academic databases and publisher platforms, including MDPI journals such as Sustainability and Recycling, Elsevier's Journal of Cleaner Production and Resources, Conservation and Recycling, Wiley's Sustainable Development and Advanced Sustainable Systems, SAGE's Textile Research Journal, and Taylor & Francis's International Journal of Fashion Design, Technology and Education and Journal of Textile Design Research and Practice,

supplemented by institutional reports (Ellen MacArthur Foundation) and primary European Union legislative texts. Search terms combined “design for disassembly,” “circular economy,” “garment construction,” “seams,” “closures,” and “textile recycling,” among related terms. Sources published between 2012 and 2026 were prioritized, with one foundational text predating this window (McDonough & Braungart, 2002) retained for its continued theoretical relevance.

This review does not follow a full PRISMA-based systematic protocol; for a more exhaustive and reproducible synthesis suitable as the primary methodological contribution of a stand-alone publication, a systematic review following an approach comparable to Ramírez-Escamilla et al. (2024), who applied PRISMA to screen circular economy strategies in the textile industry, is recommended as a next step. The present review should accordingly be read as a scoping synthesis intended to map the construction-specific literature and propose a framework and research agenda, rather than as an exhaustive census of every published study in the field.

3. Conceptual Framework

3.1 Circular economy principles applied to textiles

Despite widespread use of the term, “circular economy” lacks a single agreed definition; Kirchherr et al.'s (2017) analysis of 114 published definitions found that most emphasize a combination of reduce, reuse, and recycle activities, but that fewer explicitly foreground the systemic redesign that a genuine transition requires. Applied to fashion, the Ellen MacArthur Foundation (2017) operationalizes the circular economy through three linked principles: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating natural systems. Construction-level design choices sit primarily within the second principle: a garment's seams, closures, and material combinations determine how much value can be recovered from it once its useful life ends, and whether that recovery happens through reuse, remanufacture, or fibre recycling.

3.2 Design for Disassembly as a textile-specific construct

DfD as applied to textiles is defined by Hall et al. (2023) as the combination of materials and components in ways that allow them to be separated for recycling at end-of-life, a definition adapted from design-for-disassembly practice in the electronics and durable-goods sectors. Forst's (2020) doctoral research, carried out at the University of the Arts London's Centre for Circular Design, distinguishes between “pro-active” design for disassembly, in which blends and joins are designed from the outset with eventual separation in mind, and “re-active” design, which retrofits disassembly logic onto existing production methods. This pro-active/re-active distinction is a useful lens for the construction-level literature reviewed below, since seam and closure innovations cluster into those that require redesigning garments from scratch and those that can be layered onto conventional manufacturing with comparatively modest changes.

4. Literature Review

4.1 Seam construction and recyclability

Seams are, in effect, the primary joints of a garment, and their construction directly affects how easily a garment can be taken apart into recoverable, homogenous fabric pieces. Two related design principles recur across the literature: minimizing the number of seams and cuts to preserve larger, more valuable fabric pieces, and selecting stitch types and threads that either resist unintended failure during wear or, conversely, are designed to fail predictably and cleanly at end-of-life.

An empirical study by Ramzan et al. (2023) offers one of the few controlled comparisons of specific stitch types for disassembly purposes. Working with zero-waste pattern-cut garments (tunics and kaftans), the authors tested class 200

hand stitching, class 300 lockstitch, and class 500 overlock stitching for both seam strength and disassembly/reassembly time. Their results showed that hand-stitched seams could be disassembled fastest across all test subjects, while lockstitch seams reassembled fastest, illustrating a practical trade-off between ease of disassembly and ease of remanufacture that garment designers must weigh when selecting seam types for circular products. The same study also reports prior applied work in which eliminating unnecessary construction details and reducing material diversity allowed a men's jacket to be disassembled in as little as 1.5 minutes, indicating that disassembly time is highly sensitive to the number and type of joins used.

A more industrially scalable approach has emerged in the form of thermally or electromagnetically triggered “disassembly threads.” Stubbe et al. (2024), in a comprehensive technology-mapping white paper on textile fibre recycling, describe two commercialized systems: Resortecs' Smart Stitch and Smart Disassembly technologies, which use sewing threads engineered to melt at defined temperatures (150 °C, 170 °C, or 190 °C) inside purpose-built industrial ovens with a throughput of up to 13 tonnes per day, and Wear2's Ecostitching technology, which pairs a specialized sewing thread with microwave-based disassembly. These systems allow garments constructed on conventional sewing machines to be disassembled at end-of-life without manual cutting, provided that different components (for example, a zip placket versus a lining) are stitched using thread types matched to distinct trigger temperatures or frequencies. This represents a “pro-active” DfD strategy in Forst's (2020) terms: the disassembly method must be designed into the garment's construction sequence from the outset, but it requires comparatively little change to the machinery used in mainstream apparel manufacturing.

4.2 Closures and trims as recyclability bottlenecks

closures and trims zips, buttons, snaps, hook-and-eye fastenings, drawcords, interfacing, and labels — are frequently identified as disproportionate obstacles to recycling relative to their small share of a garment's total mass, because automated recycling lines are generally not designed to remove hard components from soft textile inputs. The DfD literature converges on two complementary construction strategies. The first is component reduction and mono-materiality: where a closure is unavoidable, using a single polymer type across the closure itself, its tape, and its stitching thread (for example, an all-polyester zip stitched with polyester thread) avoids introducing a second material stream that would otherwise need manual separation before recycling. The second is modular or detachable construction, in which components such as collars, sleeves, or linings are engineered to be removed and replaced independently, extending garment life through repairability while also simplifying eventual disassembly (see Section 4.3).

Muthu et al.'s (2012) Recyclability Potential Index (RPI), an early attempt to quantify fibre-level recyclability by combining environmental and economic gain indices, found that polyester and polypropylene scored comparatively highly on recyclability potential, while nylon 66 scored lowest among ten common textile fibres examined. Although the RPI was developed primarily to compare virgin fibre types rather than closures specifically, its logic extends naturally to trims: a polyester zip paired with a polyester shell fabric benefits from both materials sharing a single, relatively well-established recycling pathway, whereas a metal zip or a nylon closure sewn into a polyester garment introduces exactly the kind of mixed-material stream that current sorting and recycling technology struggles to process economically.

4.3 Mono-material and modular design strategies

The tension between material blending — used to achieve stretch, water resistance, or specific aesthetic effects — and recyclability is a recurring theme in the textile DfD literature. Hall et al. (2023) frame this tension through the Ellen MacArthur Foundation's “butterfly diagram,” which separates biological and technical material cycles; in an idealized circular system, natural and synthetic fibres would never be combined, giving rise to the two dominant textile circularity

strategies of mono-materiality and disassembly. In practice, however, blends are frequently functionally necessary, which Hall et al. (2023) describe as leaving the butterfly's wings "broken" in real-world textile production. Their research, alongside Forst's (2020) doctoral work, proposes that where blending cannot be avoided for performance reasons, textile designers should treat the blend itself as a designed, disassemblable system rather than an unavoidable contamination of an otherwise pure material stream — for instance, through surface treatments, structural layering, or soluble or meltable interfaces between fibre types that allow later mechanical or thermal separation.

At the garment level, modular design applies the same logic to whole components rather than fibre blends: detachable sleeves, zip-off panels, and interchangeable collars allow a single base garment to be adapted, repaired, or partially disassembled without discarding the entire piece. This overlaps with, but is analytically distinct from, zero-waste pattern-cutting research, which addresses fabric efficiency at the cutting stage rather than end-of-life separation. Townsend and Mills (2013) argue that the pursuit of zero-waste cutting can itself be a source of design creativity rather than a constraint, while a subsequent review by ElShishtawy et al. (2021) notes that zero-waste fashion design has historically developed largely as a design-led practice, with comparatively limited integration of operational research methods, such as cutting-and-packing optimization, that could scale the approach industrially. Reducing pre-consumer cutting waste and designing for post-consumer disassembly are complementary rather than identical strategies, and Ramzan et al. (2023) is notable for empirically testing both zero-waste pattern cutting and design-for-disassembly within the same set of garments, finding that the combination could address both pre- and post-consumer waste streams simultaneously.

4.4 Recycling technologies and their interface with garment construction

Construction-level design does not operate in isolation from the recycling technologies that ultimately process a garment. Two technological developments are particularly relevant to how seams and closures should be designed.

First, automated fibre sorting increasingly relies on near-infrared (NIR) spectroscopy and related optical methods to identify fibre content without relying on often-unreliable care labels. Cura et al. (2022) tested NIR-based recognition across more than 250 pre- and post-consumer fabric samples and correctly classified around three-quarters of them, with coatings, finishes, fabric thickness, and fibre blends identified as the main causes of misclassification. This matters for construction because seams and trims made from different fibres than the base fabric, or coated and finished in ways that alter surface reflectance, can cause an otherwise well-designed mono-material garment to be missorted at the point of automated recycling.

Second, the recycling processes themselves vary in how much construction complexity they can tolerate. Mechanical recycling, which shreds and cards textile waste into shorter, lower-quality fibres suitable for yarn, nonwovens, or insulation, can generally accommodate a wider range of contaminants but produces a lower-value output (Abrishami et al., 2024). Chemical recycling, by contrast, can achieve higher-value fibre recovery but is typically far less tolerant of blends; processes designed to depolymerize polyester into monomers for repolymerization, for example, work best on relatively pure polyester streams, and mixed-fibre garments generally must be pre-sorted or chemically pre-treated to separate blend components before such processes can be applied effectively (Abrishami et al., 2024; Stubbe et al., 2024). Emerging smart-textile applications add a further layer of complexity: Tadesse et al. (2025) note that embedded electronics in smart garments are frequently permanently bonded to the textile substrate, and that recycling-oriented design for these hybrid products remains a comparatively underdeveloped area relative to conventional apparel.

4.5 Regulatory and policy drivers

Construction-level circular design has historically been a voluntary, brand-led practice, but regulatory instruments are beginning to create direct commercial incentives for disassembly-oriented construction. Within the European Union, the

Ecodesign for Sustainable Products Regulation (Regulation (EU) 2024/1781), in force since July 2024, establishes a framework for setting product-level requirements on durability, repairability, and recyclability, to be operationalized for textiles through a forthcoming Digital Product Passport requiring garments to carry verifiable, product-level data on material composition and recyclability. In parallel, the revised Waste Framework Directive requires EU member states to establish mandatory textile Extended Producer Responsibility schemes, under which producer fees are expected to be eco-modulated according to how recyclable or repairable a given product is, drawing on the same underlying product data the Digital Product Passport is designed to capture. Although the precise textile-specific delegated act and implementation timeline have shifted during the legislative process, the direction of current EU policy is consistent: linking a brand's compliance costs to construction-level recyclability characteristics such as mono-materiality, disassembly ease, and accurate material labelling.

This regulatory trajectory is significant for the present review because it converts what has largely been a design-research literature, concerned with creative and technical feasibility, into a compliance and cost literature as well. Farrukh and Sajjad's (2024) qualitative study of circular economy adoption in Pakistan's textile manufacturing sector found that a lack of enforceable regulation was itself cited by firms as a barrier to circular design adoption, echoing an earlier finding by Jia et al. (2020) in their systematic review of the circular economy literature in textiles and apparel, which similarly identified weak regulatory pressure as a structural barrier to industry-wide change. Eco-modulated Extended Producer Responsibility schemes of the kind now being developed in the EU are one direct policy response to this gap, though their effectiveness in specifically incentivizing construction-level choices such as seam and closure design, as opposed to fibre sourcing, which is comparatively easier to verify, remains largely untested empirically at the time of writing.

4.6 Barriers to industry adoption

Beyond regulation, the literature identifies several recurring, non-technical barriers to construction-level circular design. Farrukh and Sajjad (2024) found that Pakistani textile manufacturers' willingness and readiness to adopt circular design practices was constrained by the complexity of existing product structures and interconnected components, echoing the closures-as-bottleneck problem discussed in Section 4.2. More broadly, systematic reviews of circular economy adoption in the textile and apparel sector point to a recurring cluster of barriers: insufficient technical expertise among design and production staff, limited financial resources for redesigning production lines around new stitch or closure technologies, and a lack of standardized definitions or metrics for “recyclable” construction, which complicates both regulatory compliance and marketing claims. Jia et al.'s (2020) systematic review situates these adoption barriers within the broader observation that circular economy research in textiles and apparel has historically concentrated on recycling and reuse at the fibre or product level, with comparatively less attention paid to the construction and assembly stage examined in this paper — a gap that the more recent DfD-specific literature (Forst, 2020; Hall et al., 2023; Ramzan et al., 2023) has only begun to address.

5. Synthesis and Discussion

Drawing the strands of Section 4 together, three observations stand out.

First, construction-level recyclability is not a single design decision but a layered set of compatible or conflicting choices spanning fibre selection, stitch and thread technology, closure type, and finishing treatments. A mono-material garment can still be rendered effectively unrecyclable by a mismatched thread, an incompatible zip, or a coating that confuses NIR sorting equipment (Cura et al., 2022); conversely, disassembly-triggered threads (Stubbe et al., 2024) can make even moderately complex, multi-material garments separable, provided the disassembly step is planned into the manufacturing sequence from the outset.

Second, the “pro-active” and “re-active” DfD strategies identified by Forst (2020) map onto a practical cost gradient. Re-active strategies — reducing seam count, standardizing thread and closure materials, and improving material labelling — can often be layered onto existing production lines with modest retooling. Pro-active strategies — engineered disassembly threads, structurally separable blends, and fully modular garment architectures — generally require more substantial redesign but offer larger recyclability gains. This suggests the field would benefit from a shared vocabulary or maturity model that lets designers and brands identify where a given construction choice sits on this gradient, an artifact the current literature does not yet provide in standardized form.

Third, regulatory instruments such as the EU's Ecodesign for Sustainable Products Regulation and eco-modulated Extended Producer Responsibility schemes are poised to convert construction-level circular design from a voluntary, reputational choice into a compliance-linked cost variable. However, the barriers-to-adoption literature (Farrukh & Sajjad, 2024; Jia et al., 2020) indicates that regulation alone is unlikely to be sufficient without parallel investment in technical capacity, standardized recyclability metrics, and closer integration between garment designers and the recyclers who will ultimately process their products.

6. Limitations

This review has several limitations that should inform how its conclusions are used. It is a narrative rather than a systematic, PRISMA-based review, and while search terms and source types are documented in Section 2, the review does not claim to be an exhaustive census of the literature; a fully systematic protocol, following an approach such as that used by Ramírez-Escamilla et al. (2024), would be needed to support publication-grade claims of comprehensiveness. The literature synthesized here is also unevenly distributed geographically, with a disproportionate share of empirical adoption-barrier studies drawn from South and Southeast Asian manufacturing contexts and a disproportionate share of design-methodology studies drawn from UK- and EU-based design research centres; this may limit the generalizability of the synthesis to other regional manufacturing and regulatory contexts. Finally, because EU textile-specific regulatory instruments — the Digital Product Passport delegated act and Extended Producer Responsibility schemes — were still being finalized at the time of writing, the regulatory analysis in Section 4.5 should be treated as a snapshot rather than a settled account, and readers preparing work for publication should verify the current status of these instruments before submission.

7. Conclusion and Future Research Directions

Garment construction — specifically seam and stitch technology, closure and trim selection, and modular or mono-material architecture — functions as a primary, and currently under-standardized, determinant of textile recyclability. The literature reviewed here indicates convergent support for a small number of construction-level strategies: minimizing seam count and material diversity, matching closures and threads to the base fabric's material family, adopting engineered disassembly threads where component separation is unavoidable, and designing blends and modular components with eventual separation in mind rather than as an afterthought. At the same time, the empirical base remains thin: relatively few studies, Ramzan et al. (2023) being a notable exception, directly measure the disassembly-time or recycle-quality consequences of specific seam and closure choices under controlled conditions.

Several directions for future research follow directly from the gaps identified above. First, there is a clear need for comparative, quantitative studies — analogous to Ramzan et al.'s (2023) stitch-type comparison — that test a wider range of seam, thread, and closure combinations against standardized disassembly-time and recycle-quality metrics, ideally across multiple garment categories such as outerwear, activewear, and denim, where material and construction demands differ

substantially. Second, research connecting construction-level design choices directly to NIR and other automated sorting outcomes, building on Cura et al. (2022), would help quantify how specific trims, coatings, and thread choices affect real-world sorting accuracy, rather than recyclability being assessed only under idealized laboratory conditions. Third, as EU Digital Product Passport and Extended Producer Responsibility requirements move toward implementation, empirical research tracking whether eco-modulated fees actually shift brands' construction-level decisions, as opposed to the more easily verified fibre-sourcing decisions, would test whether current regulatory design is well targeted at the construction-level barriers identified in this review. Addressing these gaps would help move circular garment construction from a promising but fragmented design practice toward a standardized, evidence-based component of textile circularity.

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