SUSTAINABLE AND CIRCULAR APPROACHES IN

TEXTILE ACCESSORIES

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PREFACE

The textile and apparel industry is undergoing a transformation driven by sustainability and circular economy principles due to its increasing environmental impacts on a global scale. While this transformation is often addressed through fiber types, fabric structures, and production technologies, the role of accessories elements that turn garments into complete products has long been overlooked. However, accessories such as buttons, zippers, snaps, labels, and similar components are critical elements that directly influence a product's recyclability, disassemblability, and overall environmental footprint. This work addresses textile accessories from a sustainability and circular economy perspective, highlighting the importance of the subject and emphasizing the decisive role of accessories throughout the product life cycle. Within the scope of the book, topics such as the material structures of accessories, the challenges posed by multi-component systems in recycling processes, design for disassembly approaches, mono-material solutions, and innovative sustainable practices are discussed in general terms. In doing so, the book aims to contribute to the development of more holistic and effective sustainability strategies within the textile sector.

TABLE OF CONTENTS

1. INTRODUCTION 1
2. THE IMPORTANCE OF ACCESSORIES IN SUSTAINABILITY 2
3. DESIGN FOR DISASSEMBLY 4
4. ZIPPER 7
5. BUTTON 17
6. LABEL 20
7. RIVET 24
8. SNAP FASTENER 27
9. HOOK AND EYE FASTENER 29
10. HOOK AND LOOP FASTENER 32
11. CORD END & STOPPER 33
12. BEAD, SEQUIN AND METAL EMBELLISHMENT 36
13. CONCLUSIONS AND GENERAL EVALUATION 38
14. FUTURE PERSPECTIVES 39
REFERENCES 41

LIST OF FIGURES

Figure 1. Accessory-related non-recoverable fabric section 6
Figure 2. The structure of a zipper 7
Figure 3. Manual zipper removal process 9
Figure 4. Smart disassembly system... 10
Figure 5. Automated textile disassembly and sorting system........................ 11
Figure 6. Automated textile sorting system... 12
Figure 7. Smart zipper 13
Figure 8. Waste-free zipper teeth placement system..................................... 14
Figure 9. Repairable zipper 15
Figure 10. Zipper repair system.. 17
Figure 11. Detachable button.. 19
Figure 12. Appearance after detachable accessories have been removed 20
Figure 13. Clothing label 21
Figure 14. Repurposed clothing tags 23
Figure 15. Rivet 24
Figure 16. Removing the retaining component located beneath the rivet 26
Figure 17. Snap fastener 27
Figure 18. Manual removal of snap fasteners.. 28
Figure 19. Hooks and eyes fasteners 30
Figure 20. Hook and loop fasteners.. 32
Figure 21. Cord end & stopper 34
Figure 22. Decorative sequins 36
Figure 23. Embellished fabric 36

1. INTRODUCTION

The textile and apparel industry, recognized as one of the sectors with the highest environmental impacts on a global scale, is undergoing a profound transformation driven by sustainability and circular economy principles. This transformation is most often addressed through fiber types, fabric structures, dyeing and finishing processes, or production technologies, while the role of accessories has long remained secondary. However, accessories such as buttons, zippers, snaps, rivets, labels, elastics, and sewing threads are not merely functional or aesthetic components; they are critical elements that directly determine a garment's recyclability, disassemblability, and overall environmental footprint.

Considering that approximately 120 million tons of textile waste were generated in 2024, that textile consumption is expected to increase by 63% by 2030, and that the textile industry accounts for nearly 20% of global waste, it is evident that textile waste will continue to rise rapidly worldwide and that global attention to this issue is intensifying (Sajdeh et al., 2025; Biyada & Urbonavičius, 2025).

At present, textile recycling practices predominantly focus on pre-consumer waste generated during manufacturing processes. However, the rapid growth of fast fashion production and consumption has led to a substantial increase in post-consumer textile waste, making the recycling of garments with limited reuse potential unavoidable. One of the most significant technical barriers in garment recycling is the presence of accessories composed of different materials and firmly integrated into the fabric structure. Accessories with multi-component and heterogeneous material compositions hinder separation in fiber-to-fiber recycling processes, resulting in material losses and reduced recycling efficiency. Consequently, textile sustainability emerges as a multidimensional challenge that must be evaluated not only through fabric selection but also through the design, material composition, and assembly of accessories. Each accessory type involves distinct manufacturing techniques, energy consumption patterns, and waste profiles, rendering accessory selection a critical aspect of sustainable textile design.

A genuine transformation toward sustainable fashion requires systematic innovation not only in fabrics but across all garment components. In the future, the integration of environmentally friendly material innovations, digital traceability systems, and circular design approaches will not only reduce the environmental impacts of accessories but also contribute to shaping a more equitable, transparent, and circular fashion system.

2. THE IMPORTANCE OF ACCESSORIES IN SUSTAINABILITY

Although sustainability in the textile and apparel sector is generally evaluated through fiber selection, fabric structures, dyeing and finishing processes, or production technologies, other components that constitute garments such as buttons, zippers, snaps, elastics, tapes, threads, labels, and interlinings have an impact on the environmental performance of products that is at least as significant as that of fabrics. These auxiliary materials, widely used in modern garment production, typically have complex structures formed by the combination of different material types (e.g., plastics, metals, polyester, cotton, polyurethane), which creates substantial challenges during recycling processes.

Today, in order for garment waste to be integrated into fiber-to-fiber recycling loops, accessories must first be removed individually from the fabric. Research indicates that accessory separation accounts for a large proportion of the total time required for garment sorting operations in recycling facilities. Consequently, auxiliary components such as buttons, zippers, and labels represent critical factors that directly influence a product's potential for reuse and recycling.

One of the major sustainability challenges associated with accessories is their multi-material composition. For example, the teeth of a metal zipper may be made of brass, its tape of polyester, and its carrier components of polyurethane; a button may consist of a plastic body with a metal coating; and elastic bands are often produced from blends of elastane and polyester. Such multi-component structures hinder mono-material separation and can lead to quality losses, particularly in mechanical recycling processes. For this reason, contemporary sustainable fashion literature emphasizes that not only fabrics but also the material composition of accessories must be compatible with circular economy principles.

The European Union's Sustainable and Circular Textiles Strategy for 2030 mandates that not only fabrics but all accessories used in textile products be designed in a manner suitable for recycling. In this context, the principle of *design for disassembly* has become a fundamental approach in accessory selection and application. The EU's primary objective is to ensure that, at the end of a garment's life cycle, accessories can be separated from the fabric quickly, at low cost, and without causing damage.

Accordingly, future accessory solutions in the apparel sector are based on the following principles:

- Easily detachable button and zipper systems, which enable single-step separation of metal or plastic components, thereby accelerating recycling processes and increasing sorting efficiency.
- Mono-material accessories, such as zippers made entirely from polyester or buttons composed solely of natural materials, which enhance compatibility with fiber-to-fiber recycling systems.
- Accessories produced from recycled raw materials, including zippers, tapes, elastics, and sewing threads, which support circular economy practices while contributing to a reduction in the overall carbon footprint of products.
- Solvent-free and low-chemical adhesive and interlining systems, which facilitate disassembly and reduce toxic waste generation; such next-generation adhesive technologies are actively promoted by the European Union.
- Rapidly detachable labels made from single materials or printed with water-based inks, aimed at shortening label removal processes, which are among the most time-consuming steps prior to recycling.

Taken together, these requirements demonstrate that accessories are no longer merely aesthetic or functional components but have become critical design elements that directly determine a product's recyclability, disassemblability, and compatibility with circular economy models. To achieve sustainability goals in the textile sector, the material composition, assembly methods, and life-cycle behavior of accessories must be addressed with the same level of attention as fabrics.

3. DESIGN FOR DISASSEMBLY

Considering the technical and structural challenges encountered in the recycling of textile accessories, the Design for Disassembly (DfD) approach which prioritizes the easy separation of products at the end of their life cycle has emerged as one of the most critical design strategies enabling the recovery of accessories. Design for Disassembly (DfD) originates from earlier approaches such as Design for Assembly (DFA) and Design for Manufacturing (DFM), which were first introduced in the 1970s (Ramzan et al., 2023).

DfD represents a circular design strategy that advocates designing products in a way that allows them to be easily disassembled at the end of their useful life. This approach aims to facilitate the optimal diversion of different components from the waste stream, enabling their reuse, recycling, or redirection into other value cycles (Forst, 2020).

DfD increases the reuse rate of materials and components and enables the effective separation of materials destined for technological or biological cycles. Accordingly, products developed within the DfD framework are designed with disassemblability as a key criterion, positioning the designer as the primary actor responsible for integrating these considerations into the product (Ramzan et al., 2023).

One of the key contributors to the development of disassembly-oriented design in textiles is Dr. Joseph Chiodo, whose work on the concept of Active Disassembly gained widespread academic and policy attention following its recognition in a report published by the Ellen MacArthur Foundation. This report emphasizes that a fundamental prerequisite for transitioning to a circular fashion system is the alignment of garment design with recycling processes, demonstrating that waste generation can be prevented at the design stage. Chiodo's approach argues that design strategies enabling product reuse and component separation lie at the core of textile circularity. (https://www.ellenmacarthurfoundation.org/publications/a-new-textiles economy-redesigning-fashions-future).

Goldsworthy and Ellams (2019) highlight that design should be considered an integral component of the circular economy model. Their work demonstrates that a life-cycle-oriented and systematic stakeholder approach offers a unique opportunity to examine the knowledge designers must possess when designing for circularity (Goldsworthy and Ellams, 2019).

Supporting this perspective, Bocken et al. (2016) argue that circular elements must be incorporated at the early and speculative stages of product development, emphasizing that effective implementation of Circular Design and the Circular Economy requires close collaboration among science, industry, and design disciplines (Bocken et al., 2016). Similarly, Moreno et al. (2016) propose that designers should evolve from being mere “object creators” to acting as “solution providers” (Moreno et al., 2016).

Strengthening the design phase of the product life cycle and integrating findings generated at this stage into the process enables end-of-life planning to become an embedded component of product development. One study examining the application of Design for Disassembly (DfD) in textile production demonstrates how methods that facilitate the easy separation of fibers, auxiliary materials, and accessories enhance garment recyclability. Research findings indicate that fabric recovery rates in cotton and polyester garments designed according to DfD principles reach up to 85%, whereas this rate remains at approximately 60% in conventional products. In addition, accessories such as buttons and zippers were reported to be largely detachable without damaging the fabric. Furthermore, the DfD

approach was found to reduce greenhouse gas emissions by approximately 30% and water consumption by 25% compared to conventional garments. These findings support the conclusion that DfD applications constitute an effective and feasible strategy for enhancing circularity in the textile sector (Politi et al., 2024).

A case study conducted by Kumar et al. (2021) further confirms the effectiveness of incorporating disassembly and dismantling activities into the early stages of the product life cycle. The study emphasizes that integrating recycling principles into the early phases of design is more advantageous than applying recycling practices only at the end of a product’s life, and that this approach contributes to reductions in CO_2 emissions. Moreover, it highlights that systematic dismantling of end-of-life products based on a predefined disassembly plan offers significant potential for reducing the overall amount of waste generated (Kumar et al., 2021).

Conventional buttons, rivets, and zippers are predominantly metal-based and are technically difficult to separate from fabrics during recycling processes. In traditional practices, the removal of these accessories is often achieved by cutting the fabric, resulting in the disposal of the accessory-containing areas and increased material losses. Although roughly cutting out sections containing buttons, zippers, and rivets may shorten processing time, it increases the amount of unrecoverable fabric and consequently reduces recycling efficiency.

Figure 1. Accessory-related non-recoverable fabric section

To address this issue, detachable button and rivet solutions have been developed to enable the separation of metal accessories from garments during recycling processes. This innovative system allows metal accessories to be easily removed using a simple tool, thereby eliminating separation challenges in garment recycling facilities. While garments with standard metal accessories typically generate approximately 30% waste prior to recycling limiting recycling efficiency to around 70% the use of detachable buttons and rivets enables complete removal of metal accessories from the product. As a result, fabric losses caused by metal accessories are prevented, making recycling ratesof up to 100% achievable (https://www.ykk.com.tr/kataloglar/brosurler/MonomaterialDetachableButtonRivet/Mono_material_Detachable_Button_Rivet.pdf).

4. ZIPPER

The zipper is one of the most widely used functional accessories in textile products. Although it may appear to be a simple closure system, it actually has a multi-component and complex structure consisting of a tape, teeth (elements), slider, stoppers, and various surface treatments or coatings.

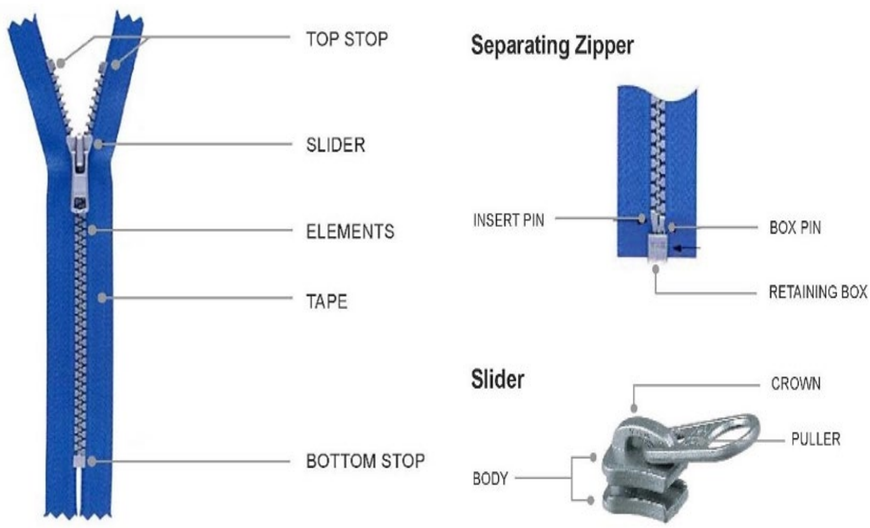


Figure 2. The structure of a zipper
(https://ykkamericas.com/the-structure-of-a-zipper/)

Tape: The tape forms the structural foundation of the zipper and is typically manufactured from textile materials such as polyester, nylon, or cotton. Due to its favorable balance of flexibility, strength, and sewability, polyester is the most commonly used material for zipper tapes. The tape features a specific woven or knitted structure designed to hold the teeth securely. While this structure enables the zipper to be sewn into the garment, it also increases the degree of integration between the zipper and the fabric, thereby complicating disassembly at the end-of-life stage.

Teeth (Elements): The teeth, which represent the most characteristic component of the zipper, may be produced from metal (brass, aluminum, or nickel-plated steel), molded plastic, or coiled nylon. Because these materials differ significantly in terms of melting point, chemical structure, and hardness, they cannot usually be processed within a single polymer stream during recycling. This material heterogeneity constitutes one of the primary reasons why zippers are considered particularly complex components from a recycling perspective.

Slider: The slider is the mechanical component that enables the teeth to interlock or disengage. It is typically manufactured from metals such as zinc alloys or brass, or from high-performance plastics such as POM (acetal). Small components such as the internal channel design, the locking mechanism, and the puller within the slider make the zipper technically complex. The coexistence of multiple materials within the slider assembly further complicates separation processes.

Top and Bottom Stops: Top and bottom stops, which may be made of metal or plastic, are positioned at the ends of the tooth chain to prevent the slider from running off the zipper.

Puller: The puller, attached to the slider, may be produced from metal, plastic, silicone, or textile materials. Brand-specific shaping and surface treatments (e.g., nickel or chrome plating, painting) introduce additional material diversity, increasing recycling incompatibility and further complicating mechanical separation.

The multi-material and multi-layered nature of zippers significantly hinders efficient separation during recycling, rendering zipper recycling technically complex. Furthermore, certain zipper types incorporate resin coatings, waterproof membranes, laminations, or thermoplastic reinforcement zones. While these features enhance mechanical and functional performance, they introduce additional heterogeneous layers that substantially reduce disassembly and recyclability.

Manual Separation: Manual disassembly aims to separate zippers from garments in a manner that preserves both the zipper and the fabric. This approach is particularly common in small-scale recycling facilities, pilot projects, or contexts where automated separation systems are not available.

In this process, the stitching at both ends of the zipper is carefully opened using sharp scissors, knives, or seam rippers. The use of seam rippers allows thread removal without damaging the fabric. Once the tape is detached from the garment, metal or plastic teeth may be removed using pliers if required. If the zipper is intended for reuse, the slider and stoppers are left intact. The separated zipper and fabric components are then cleaned of residual threads or linings and sorted according to material type (e.g., metal, plastic, polyester) before being directed to appropriate recycling streams.

Although manual zipper removal is slower than automated systems and entails high labor costs, it offers advantages such as high material recovery rates, low investment requirements, and suitability for prototyping and training applications. Consequently, this method remains relevant in the recycling of garments such as denim products, jackets, and coats within sustainability-oriented workflows.

Figure 3. Manual zipper removal process (https://craftingagreenworld.com/articles/reclaim-zippers-old-pairs-jeans/, https://madeonjupiterleatherlab.com/products/zipper-teeth-remover?srsltid=AfmBOorRKtDQsm5S22RFo_eg8iaT8EE37eIqV2zWzeQ0fLSNyLQDEQIz)

Existing Automated and Semi-Automated Separation Systems: Zippers and buttons significantly complicate garment recycling because their removal typically requires manual intervention, making the process both time-consuming and costly. To address this challenge, Resortecs has developed two complementary technologies. The first is Smart Stitch™**,** a thread composed of 16 filaments that dissolves at elevated temperatures. When used in conventional seams, this thread enables entire garments to be easily disassembled, allowing fabrics to be reused repeatedly without the need to produce new material. The second innovation, Smart Disassembly™**,** is the world's first thermal disassembly system. This fully automated process enables recyclers to remove zippers, elastic bands, and other components that hinder recycling. Recycling rates of up to 95% can be achieved using this approach. Together, these technologies demonstrate the industrial feasibility of the Design for Disassembly (DfD) principle by creating a planned circular system that begins with accessory and stitch selection and extends through the product's end-of-life stage.

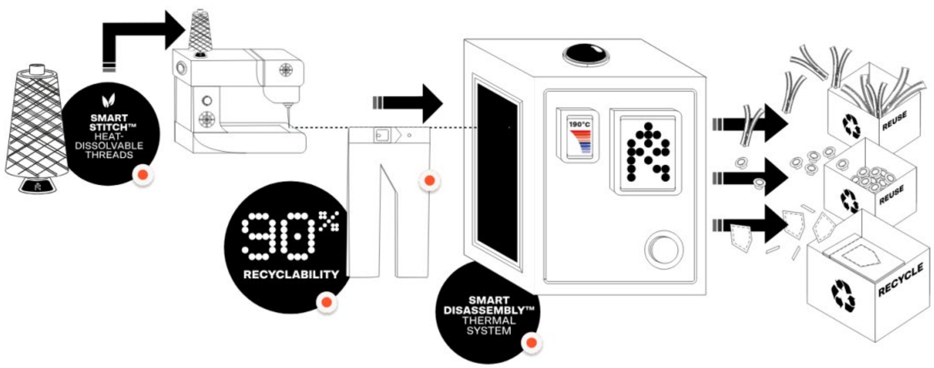


Figure 4. Smart disassembly system
(https://resortecs.com/technology/)

A research team within the Golisano Institute for Sustainability (GIS) at Rochester Institute of Technology (RIT) is developing a fully automated system capable of operating at high speed and high volume to identify, classify, and disassemble garments in response to the growing global textile waste problem. Using artificial intelligence (AI) and laser technologies, components such as zippers, logos, and mixed-material elements are detected and removed. A robotic arm separates the "clean" (pure) portion of a shirt from areas containing prints, logos, or accessories, enabling the uncontaminated fabric to be reused in other applications (https://www.rit.edu/news/new-rit-technologies-help-minimize-global-textile-waste?utm_source).

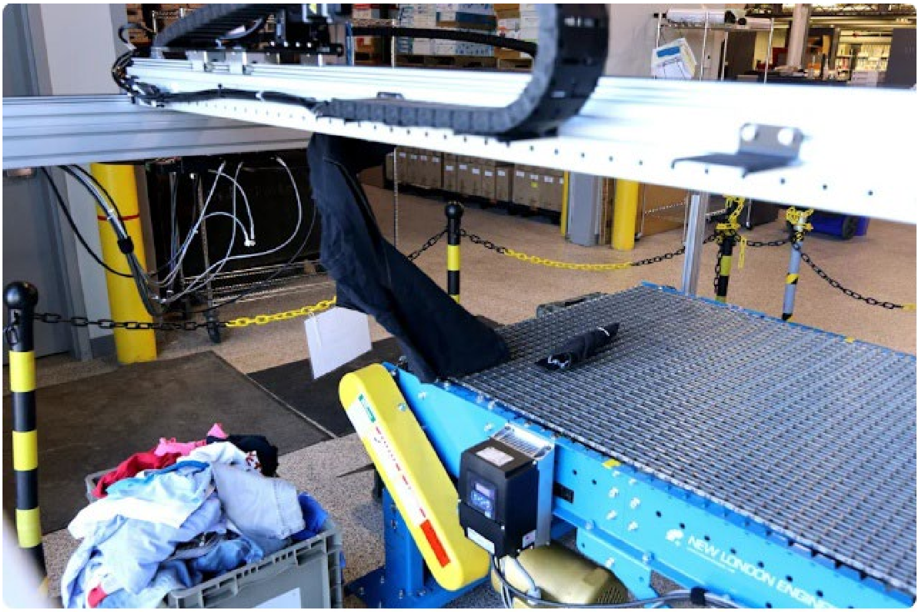


Figure 5. Automated textile disassembly and sorting system (https://www.yahoo.com/news/articles/rits-machine-tackles-one-biggest-161056698.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAHR_Vja0FPuK-Jb4PyyMkJsOXVzZOx2bCH6u_UvV33p28Mb5OalktWsgKsmE7e3vlK33KxkqOfvJBZRsapqdLW75QdYvd9uWdaj22QmKIOrbD54pBURsCaTJC0JE0owNUJxhcnfsfNfS-xdS1K3aCM9NaIKjgpSu9smIuvKzNPqe)

Similarly, a fully automated textile sorting facility established in Malmö, Sweden, through the collaboration of STADLER and TOMRA, utilizes NIR sensors and optical systems to classify textile waste at high throughput. By separating accessories such as zippers, buttons, and labels prior to recycling, the system enables the recovery of high-purity recyclable raw materials. This example highlights the critical role of automated separation systems in achieving scalability and material quality in textile recycling.

Figure 6. Automated textile sorting system (https://stadler-engineering.com/company/news/detail/stadler-and-tomra-deliver-the-worlds-first-fully-automated-textile-sorting-plant-in-malmoe-sweden)

Automated separation systems accelerate recycling processes by replacing manual disassembly, offering scalability, reduced labor requirements, and high processing speeds. Integrated with imaging technologies and Near-Infrared (NIR) sensors, these systems can automatically identify fabric and accessory types. However, their main limitations include high investment costs and a certain margin of error in detecting specific accessories.

Magnetic and Thermal Separation: In zippers with metal teeth, metal components can be effectively separated after shredding using magnetic separators. While this method is simple and efficient, it is not applicable to plastic or nylon zippers. More advanced but still limited approaches involve chemical or thermal pre-treatments aimed at melting or dissolving thermoplastic zipper components. Due to high energy requirements and the risk of damaging textile fibers, these methods have not yet achieved widespread industrial adoption.

Solutions for Enhancing Zipper Circularity: The multi-layered structure of zippers requires high precision during manufacturing, while the use of multiple materials and strong integration into garments creates substantial challenges at the recycling stage. In this context, redesigning zippers according to mono-material, easy disassembly, and Design for Disassembly principles has emerged as a critical requirement for the development of sustainable textile products.

Producing all zipper components such as tape, teeth, and slider from the same polymer or material family (mono-material approach) eliminates the need for additional separation at the end-of-life stage and allows direct integration into recycling streams, offering a significant advantage for circular economy implementation. While this approach enhances recyclability and simplifies waste management, it requires careful balancing of material compatibility, mechanical performance, and aesthetic requirements during design and production.

The use of materials derived from recycled PET bottles in zipper tapes, along with options made from 100% recycled polyester, enables compatibility with polyester garments within the same recycling stream, reinforcing mono-material advantages and positioning such zippers as exemplary solutions for circular economy transitions.

The integration of NFC chips into zipper sliders allows both users and recycling facilities to access detailed product information, including production date and location, material composition, care instructions, and repair guidelines.

Figure 7. Smart zipper
(https://www.ykk.com/english/newsroom/g_news/2024/20241115.html)

In conventional zipper production, teeth are continuously fixed along the tape, resulting in excess teeth being cut off and discarded when zippers are trimmed to length. A developed method eliminates post-cutting tooth waste by placing teeth only in the required length, thereby increasing production efficiency, reducing resource consumption, and lowering environmental impacts.

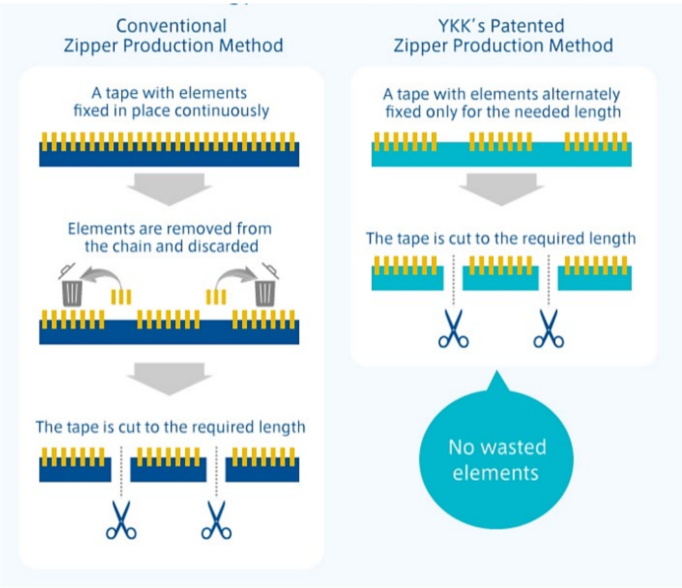


Figure 8. Waste-free zipper teeth placement system
(https://www.ykkfastening.com/itsnotjustazip/vol02/)

As textile production and consumption continue to grow, environmental impacts increase largely due to insufficient repair, reuse, and recycling practices. For complex and variable components such as zippers, particularly in low- and mid-priced garments, the cost and effort associated with traditional repairs have often outweighed the value of the product itself.

Designing zipper components in modular and detachable forms rather than permanently sewing them into garments enables accessories to be easily removed and directed into material-specific recycling streams at the end of the product's life cycle. At the same time, this approach supports repair, refurbishment, and reuse strategies aimed at extending garment lifespan. While offering advantages such as durability, ease of repair, and waste reduction, modularity and disassembly requirements necessitate changes in design, sewing, and manufacturing processes, thereby requiring careful planning in terms of cost and durability.

As an illustrative example, zippers have been designed with top stops that allow the slider to be easily removed. In cases of accidental slider breakage, this design enables repair through slider replacement alone, eliminating the need to replace the entire zipper. Such repairable and durable garments contribute to reducing the environmental footprint of the textile industry.

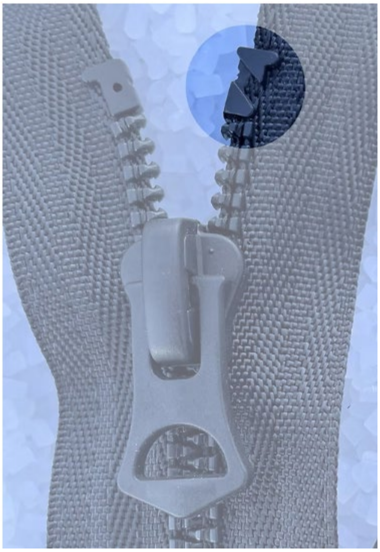
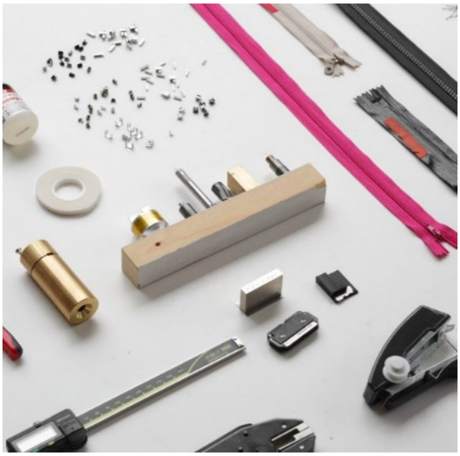


Figure 9. Repairable zipper
(https://www.nyguard.com/nylife)

An innovative modular zipper repair system has been developed to provide a circular-economy-oriented repair infrastructure. The system operates via a digital user interface that identifies zipper type, selects the required spare parts, and guides the repair process step by step. Repairs that traditionally take approximately 40 minutes can be completed in as little as 10 minutes. Designed to be modular and compatible with different zipper and garment types, the system allows users to replace only the damaged component (e.g., slider or top stop) without removing or re-sewing the entire zipper, thereby saving time and labor while minimizing material waste.



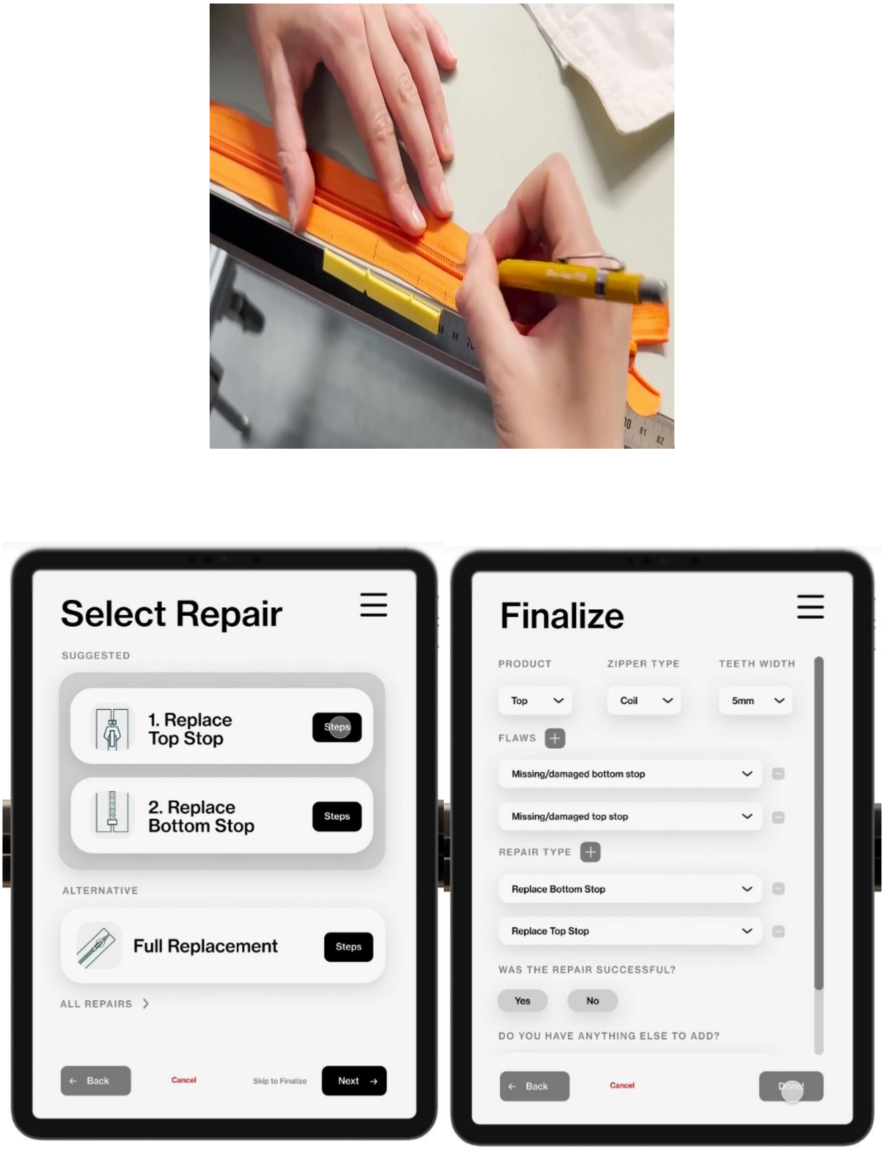


Figure 10. Zipper repair system
(https://www.gentle.systems/page/zipper-repair)

5. BUTTON

Buttons are fundamental mechanical accessories used in textile and apparel products to fasten two pieces of fabric, ensure garment closure, and serve as aesthetic complementary elements. They are widely applied in shirts, trousers, jackets, coats, skirts, and outerwear. Beyond their functional role, buttons are also regarded as important design components that reflect brand identity and design language.

Buttons used in the textile sector can be manufactured from a wide range of materials, and this diversity leads to significant differences in recycling processes. The most common button types include:

- Plastic-based buttons: produced from polymers such as polyester, polyamide (nylon), polyacetal (POM), ABS, and acrylic. These buttons offer low cost and extensive color and shape variability; however, they may cause fiber contamination during recycling.
- Metal buttons: composed of brass, aluminum, steel, zinc alloys, or nickel-plated metals. They are durable and technically recyclable, but their strong fixation to fabrics complicates separation processes.
- Buttons made from natural materials: produced from mother-of-pearl, wood, bone, horn, or coconut shell. Owing to their bio-based structure, they are environmentally advantageous; however, they may present limitations in terms of supply consistency and standardization.
- Composite and coated buttons: consisting of plastic cores with metal coatings or multilayer structures. These buttons represent the most problematic group in recycling due to their complex material composition.

Manual separation: The most widely used method for button removal is manual separation. In this approach, buttons are detached from garments by cutting the sewing threads using seam rippers, scissors, or cutting tools. Manual separation enables high-precision removal without damaging the fabric and is therefore preferred for high-quality garments and during pre-sorting stages. Nevertheless, due to its labor-intensive and time-consuming nature, this method has limited economic feasibility in large-scale recycling facilities.

Post-shredding separation: In some facilities, garments enter mechanical shredding lines without prior button removal. In such cases, metal buttons can be partially detected and separated using magnetic separators after shredding. Plastic buttons, however, mix with textile fibers, leading to contamination and reduced quality of the recovered fibers. Although this approach is relatively fast, it disrupts fabric integrity and lowers secondary raw material quality, making it a less desirable solution.

Automated and semi-automated separation systems: In advanced recycling facilities, buttons can be detected using camera systems, optical sensors, and Near-Infrared (NIR) technologies. Image-processing and artificial intelligence–based systems identify the location of buttons and enable targeted cutting of the relevant areas or removal via robotic arms. While these systems offer advantages in terms of scalability, their widespread adoption remains limited due to high investment costs and technical challenges associated with detecting small components.

Sustainable Solutions: In recent years, several sustainable design approaches have been developed to enhance the compatibility of buttons with recycling processes. Mono-material buttons, produced from the same polymer as the main fabric, improve material compatibility and facilitate fiber-to-fiber recycling. Easily detachable button systems, enabled by dedicated mechanisms or simple tools, allow buttons to be removed in a single step, preventing fabric loss and increasing recycling efficiency.

Figure 11. Detachable button (https://www.amazon.com/Perfect-Instant-Buttons-Replacement-Removable/dp/B08SW6W4WP?th=1)

Figure 12. Appearance after detachable accessories have been removed (https://www.ykk.com/english/csr/eco/report/pdf/2025/this_is_YKK_2025_all_en.pdf)

In addition, buttons manufactured from recycled raw materials (e.g., rPET or recycled metals) reduce the use of virgin resources and associated carbon footprints. Coating-free and single-piece designs limit environmental risks arising from metal coatings and chemical surface treatments, while bio-based and biodegradable alternatives such as buttons made from wood, mother-of-pearl, PLA, or cellulose-based materials offer sustainable solutions by reducing environmental burdens at the end of the product life cycle.

6. LABEL

Labels used in garments are informative and promotional textile accessories that convey product identity, usage characteristics, and mandatory consumer information. They represent one of the smallest yet most critical components enabling traceability throughout a garment's life cycle, from production to consumption. Depending on their function, labels may include brand labels, size labels, care (washing) labels, fiber composition labels, and price or barcode labels. Produced from a variety of materials during manufacturing such as woven or knitted fabrics, printed textiles, cardboard, or plastic films labels serve not only informational purposes but also play an important role as aesthetic and marketing elements that reinforce brand identity.

Garment labels do not merely communicate size, material content, or care instructions; they also carry essential information related to sustainability and recycling. Recycling symbols, recycled content percentages, production standard markings (e.g., GRS, OEKO-TEX), and QR codes printed on labels inform consumers about environmental impacts and recycling pathways. In addition, eco-friendly washing and life-extension guidelines, as well as instructions for accessory separation, facilitate the garment’s proper integration into recycling streams at the end of its life cycle.

Figure 13. Clothing label
(https://www.oeko-tex.com/fileadmin/user_upload/OEKO-TEX_Labelling_Guide.pdf)

Each label functions as a key information carrier that ensures traceability throughout a garment’s life cycle. However, a common consumer practice is the removal of garment labels for aesthetic or comfort reasons. This practice leads to significant challenges during recycling, as garments without labels cannot be accurately identified in terms of fiber type, blend ratios, or recycling classification. As a result, such products are often treated as mixed waste or excluded entirely from recycling processes.

Therefore, preserving labels on garments is essential not only for consumer information but also for material traceability, recycling classification, and circular economy applications. In this sense, the label functions as the garment's identity; without this identity, effective material recovery becomes impossible.

Labels may be attached to garments by sewing, adhesive bonding, or heat-transfer methods. The choice of material and application technique is determined by durability, cost, appearance, and sustainability criteria. Although labels account for only a small fraction of a garment's total weight, they are among the components that can negatively affect recycling efficiency. The inclusion of different fibers, adhesives, films, or coatings introduces material heterogeneity into recycling processes. Consequently, material selection at the label design stage directly influences a garment's recyclability at the end of its life cycle.

Collection and Pre-Sorting Stage: Because labels are typically sewn into garments, they are not easily detected by automated systems and therefore require manual pre-inspection. If a label is produced from a fiber type different from that of the main fabric (e.g., a polyester label in a cotton shirt), separation may be necessary. Recently developed optical and NIR (Near-Infrared) sensor-based sorting systems, however, are capable of identifying different material components on garments and detecting the presence of labels.

Mechanical Recycling (Shredding / Fiber Recovery): If a label is made from the same fiber type as the garment (e.g., rPET fabric with an rPET label), it may enter mechanical recycling together with the fabric. Conversely, labels composed of different fiber types (e.g., a cotton garment with a polyester label) cause fiber contamination in mechanical systems, leading to reduced fiber quality.

Chemical Recycling (Depolymerization / Dissolution): Certain types of labels particularly those based on polyester, nylon, or TPU may be processed through chemical recycling. In these processes, thermoplastic materials are depolymerized or dissolved to obtain new polymer chips, which can subsequently be re-spun into fibers.

Thermal Recycling and Energy Recovery: If the label material cannot be recycled through either mechanical or chemical processes, thermal recycling (energy recovery) is applied. In this approach, labels are incinerated at high temperatures and converted into energy. This method is used as a last option due to its high carbon emissions.

Sustainable Alternatives and Innovations: Some luxury brands and designers have begun incorporating labels into reuse or upcycling projects. Brand or care labels recovered from used garments are repurposed as decorative elements in new designs. This practice contributes to both aesthetic and cultural sustainability.

Figure 14. Repurposed clothing tags
(https://tr.pinterest.com/pin/5559199537004598/)

Approaches aimed at enhancing sustainability in label recycling address both material selection and information delivery methods. In this context, woven labels made from recycled polyester (rPET), derived from post-consumer PET bottles, ensure material compatibility with rPET-based fabrics and support textile-to-textile recycling processes. In addition, bio-based or biodegradable label materials (e.g., TENCEL™, PLA films, and organic cotton) reduce environmental burdens at the end of the product life cycle. To minimize physical label usage, laser-engraved or directly printed labels eliminate the need for additional materials, thereby reducing waste generation. As a recent development, EU Digital Product Passport (DPP) applications enable care instructions, content information, and traceability data to be provided digitally without reliance on physical labels. This approach enhances information transparency while significantly reducing label-related waste.

7. RIVET

A rivet is a small metal fastening component used in garment production to permanently join two or more layers of fabric. Rivets are commonly applied in shirts, trousers, jackets, bags, and workwear, particularly at locations exposed to high tensile or tearing forces (e.g., pocket corners, belt loops, and stress-prone seam ends). In addition to their functional role, rivets are also regarded as decorative design elements and thus constitute important features reflecting brand identity within the fashion industry. A rivet typically consists of two components:

- Post: the cylindrical part that passes through the fabric from the reverse side.
- Cap: the visible upper component that provides the aesthetic appearance.

During assembly, these two parts are joined by a pressing process, securely fixing the fabric layers together.

Figure 15. Rivet (https://www.buttoncare.com/clothing-rivets.html?srsltid=AfmBOopP_yw4p-SYSHQAqCUW1R_SA-6oByEaXAW2OqppuPSM3AR-HeGY)

The most commonly used materials in rivet production include brass, which stands out due to its corrosion resistance and ease of formability; aluminum, which is preferred for its lightweight structure, resistance to oxidation, and suitability for color coating; and stainless steel, which is used particularly in industrial applications owing to its high strength and long service life. Copper is widely used in traditional denim rivets and develops a characteristic "vintage" appearance over time through oxidation. Zinc/nickel alloys (Zn–Ni) offer cost and durability advantages; however, they pose certain environmental risks due to the chemicals involved in surface coating processes.

Recyclability: Metal rivets (copper, brass, aluminum, and steel) are technically recyclable materials. The primary challenge, however, lies in the fact that these components are strongly integrated into garment structures, making their practical, rapid, and cost-effective separation prior to recycling difficult. Because rivets are firmly fixed to fabrics, separation often requires manual removal; yet, as this approach is not economically viable in large-scale recycling operations, areas containing rivets are frequently cut out and excluded from the recycling stream.

When garments containing rivets enter recycling lines, they may damage blades and equipment in mechanical shredding machines, cause fiber contamination due to the incorporation of metal particles into the fiber mix, and even if detected by magnetic separators are often directed to mixed metal waste streams rather than to dedicated recovery processes.

Manual Separation: Manual removal involves extracting rivets using pliers, cutting tools, or dedicated removal devices. Although this method provides high separation accuracy, its high labor and time requirements limit its application to small-scale facilities, products with high reuse value, or preliminary sorting stages. As illustrated in Figure X, a metal plate with two holes is located beneath the rivet. By gripping and compressing this component with plier-like tools, it can be fractured, allowing the rivet to be easily detached from the fabric. Following this process, only a small hole remains in the garment (Figure 16).

Figure 16. Removing the retaining component located beneath the rivet

Magnetic Separation: After shredding, rivets containing metal can be detected and separated using magnetic separators within recycling lines. However, this method does not remove the rivet from the garment prior to shredding; it merely collects metal fragments afterward, which are generally routed to mixed metal waste streams.

Sustainability-Oriented Approaches: Within the scope of sustainable design, innovative rivet systems incorporating screw- or clip-based mechanisms, mono-material designs (manufactured from a single metal or metal–metal compatible combinations), and detachable or modular connection structures have been developed. These approaches enable rivets to be separated easily, rapidly, and economically at the end of a product's life cycle. The use of recycled metal rivets such as those produced from 100% recycled brass or aluminum and verified by GRS certification aims to reduce environmental impacts, while nickel-free surface treatments limit allergy risks and heavymetal-related waste generation. In addition, some manufacturers have developed plastic-based alternative systems that deliver rivet-like aesthetics supported by stitching, thereby maintaining functional durability while facilitating recycling processes.

8. SNAP FASTENER

Snap fasteners, also referred to as press buttons, are mechanical fastening components used to join two fabric layers either temporarily or permanently. These systems close when pressed together and open when pulled apart, offering an aesthetic alternative to conventional buttons while providing a high level of user comfort. They are commonly used in products such as baby clothing, jackets, shirts, and sportswear.

Figure 17. Snap fastener (https://www.terziyedair.com/urun/9-5mm-sedefli-citcit-100-adet?srsltid=AfmBOooayg8EaYLqMkZzWg4dSRPColEhAZsT4RFTH5F1unpAXDSJpSja)

The materials used in the production of snap fasteners are generally metal- or plastic-based. Metal snap fasteners (e.g., brass, steel, aluminum, nickel, and copper) are widely preferred due to their high durability and long service life. Although these metals are technically recyclable, their separation from fabrics during garment recycling is difficult, which reduces overall process efficiency. Plastic-based snap fasteners, on the other hand, offer advantages such as lightweight structure, color versatility, and low cost;

however, they tend to cause fiber contamination during recycling, leading to adverse environmental impacts.

Manual Separation: Manual separation is the most commonly applied method for removing snap fasteners during recycling. In recycling facilities, areas containing snap fasteners are typically cut out by hand. In higher-quality garments (e.g., denim products or jackets), snap fasteners may be removed using pliers or cutting presses. Despite its effectiveness, this process is time-consuming and labor-intensive, limiting its feasibility at an industrial scale.

Figure 18. Manual removal of snap fasteners (https://www.burieddiamond.com/blog/2021/6/29/how-to-remove-heavy-duty-snaps-tutorial-removing-dritz-heavy-duty-snaps)

Mechanical Separation: Before garments enter shredding lines, they may be screened using vibrating sieves or cutting systems. Magnetic separators can effectively separate snap fasteners containing ferromagnetic metals (such as steel or iron). However, snap fasteners made of brass, aluminum, or plastic cannot be detected using this method. While suitable for high-throughput operations, this approach is effective only for magnetic metals.

Automated Visual Separation: In advanced recycling facilities, optical recognition systems (RGB and NIR sensors) combined with artificial intelligence–based imaging technologies are employed. These systems detect snap fasteners based on surface reflectivity and shape differences, identifying metallic regions on garments. Robotic arms or cutting systems then isolate these areas. Although still under development, this method represents a promising direction for automated separation.

Thermal Separation: For garments containing plastic snap fasteners (e.g., POM or nylon), low-temperature heating may be applied to separate the fasteners from the fabric. This method is not suitable for metal snap fasteners, as thermal expansion may damage the fabric. Additionally, there is a risk of fabric degradation and a certain level of energy consumption is required.

Sustainability-Oriented Approaches: Several innovative approaches have been developed to improve the sustainability performance of snap fasteners. Detachable snap systems, incorporating mechanical screw- or clip-based structures, enable easy removal prior to recycling. Mono-material designs, in which the snap fastener is produced from the same material as the base fabric, enhance material compatibility in recycling processes. The use of recycled metals certified under GRS or RCS (e.g., brass, aluminum, steel) helps reduce environmental burdens. Coating-free surface treatments eliminate the risk of toxic waste associated with nickel or chemical plating. More recently, bio-based plastics (such as bio-POM or PLA) have gained attention as sustainable alternatives due to their compostability and lower carbon footprints.

9. HOOK AND EYE FASTENER

Hooks, eyes, and clasps are mechanical fastening components used to join two parts of a garment. These accessories are typically small in size, manufactured from metal or plastic materials, and provide either permanent or temporary closure functions. They are widely used in womenswear (e.g., dresses, corsets, bras, skirts), tailored garments, belts, jackets, and workwear. Structurally, they consist of a hook element and a corresponding eye component; garment closure is achieved by engaging these two parts. Some designs incorporate paired hook-and-eye systems or spring-loaded locking mechanisms.

Figure 19. Hooks and eyes fasteners
(https://tekstilsayfasi.blogspot.com/2020/12/agraf-nedir-agraf-ne-demek.html,
https://www.williamgee.co.uk/shop/prym-trouser-skirt-hook-and-bars-9-5mm-silver/)

A variety of materials are used in the production of hooks, eyes, and clasps, each associated with different sustainability implications. Steel and stainless steel enable the production of long-lasting accessories due to their high durability and dimensional stability and are technically recyclable; however, their strong attachment to garments complicates removal during recycling. Brass and copper alloys are favored for their flexibility and decorative qualities, although chemicals used in surface coating processes may pose environmental risks. Aluminum stands out for its lightweight nature and corrosion resistance, while also contributing to sustainable production through its relatively low carbon footprint. In contrast, plastic materials (such as nylon, POM, and ABS), despite offering economic advantages and color versatility, are unfavorable from a recycling perspective as they may cause fiber contamination. Bio-based polymers (e.g., PLA and bio-POM), owing to their biodegradable properties, are increasingly considered promising sustainable alternatives for future applications.

In recycling processes, the separation of hooks, eyes, and clasps from garments depends on both material type and fixation method. These components are commonly sewn, riveted, or press-attached to fabrics. During separation, the primary objectives are to minimize mechanical damage to textiles while enabling effective metal recovery.

Manual Separation: Manual removal is the conventional method and is still widely applied in many recycling facilities. Sewn hooks are detached using scissors or seam-ripping tools, while riveted or firmly fixed clasps are removed with pliers. This approach is feasible for products with a limited number of components; however, it is labor-intensive and cost-prohibitive for large-scale processing.

Mechanical / Magnetic Separation: Hooks containing steel or iron can be separated from shredded textile streams using magnetic separators, making this method effective for ferromagnetic metals. Brass, aluminum, and plastic hooks cannot be detected magnetically and therefore cannot be separated using this approach. Large-scale recycling facilities often employ automated vibrating screens combined with magnetic separation lines.

Visual and AI-Based Separation: Camera systems and NIR sensors are used to detect metallic reflective surfaces on garments. Through visual analysis based on metal reflectance, hooks or clasps can be identified, and the corresponding areas are marked for separation using robotic arms or laser cutting systems. Although still under development, this method represents the future of automated accessory separation.

Thermal or Chemical Separation (Selective Softening): This approach is particularly applicable to plastic hooks and clasps. At low temperatures, softening or solvent-induced separation allows plastic components to be detached from fabrics. This method is not suitable for metal components. Environmentally friendly solvents, such as bio-based alternatives, are preferred to minimize environmental impact.

Sustainability-Oriented Approaches: In sustainable production, priority is given to material compatibility, recyclability, and ease of disassembly of hooks and clasps. The use of recycled aluminum and steel certified under GRS or RCS contributes to reducing carbon footprints. Coating-free designs that favor natural metal surfaces instead of nickel, chromium, or zinc plating help prevent chemical waste generation. In particular, mono-material-compatible accessories produced from the same polymer as the base fabric (e.g., PET fabric with PET hooks) facilitate separation and recycling processes. Detachable systems incorporating screw or clip mechanisms enhance removability at the end of the product's life cycle, while bio-based clasps made from materials such as bio-POM or PLA are emerging as compostable alternatives.

10. HOOK AND LOOP FASTENER

Hook-and-loop fasteners consist of two complementary textile surfaces. One surface is composed of stiff, micro-scale fibers formed into hook structures, while the opposing surface contains softer, more flexible loop-shaped fibers. When these two surfaces come into contact, the hooks mechanically engage with the loops, creating a temporary yet sufficiently strong fastening. The system is designed for repeated opening and closing and is typically manufactured from polyester, polyamide (nylon), or blends thereof.

Despite offering high functionality and long service life in garments, hook-and-loop fasteners are among the most complex accessories in terms of recycling. This complexity arises from material heterogeneity and fixation methods, as they are commonly attached by stitching or by heat-activated adhesive bonding. Consequently, hook-and-loop fasteners introduce both mechanical and thermal challenges in recycling processes.

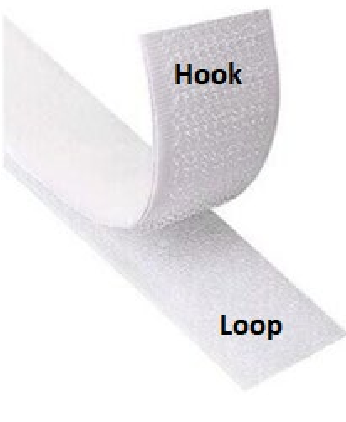


Figure 20. Hook and loop fasteners (https://www.hepsiburada.com/enzelo-beyaz-cirt-cirtli-bant-5-metre-2-cift-tarafli-amerikan-fermuari-2-cm-genislik-cirt-bant-beyaz-pm-HBC0000162J83)

Manual Separation: In manual removal, the fastener tape is detached from the garment by cutting along the stitch line using scissors or seam-ripping tools.

Mechanical Separation: When garments containing hook-and-loop fasteners enter shredding lines, the fastener area is often identified as a region with stiffer fibers. After mechanical size reduction, polyester or polyamide tape fragments may be separated using density-based separation methods. However, when the fastener and the base fabric share similar densities (e.g., PET fabric combined with PET fastener), effective separation becomes difficult.

Thermal and Chemical Separation: For fasteners fixed with adhesives, low-temperature heating or solvent-based separation techniques may be applied to release the fastener fibers. While these methods enable separation, they require solvent recovery. Bio-based solvents (e.g., lactic acid derivatives) represent more environmentally friendly alternatives to conventional chemical agents.

Sustainability-Oriented Approaches: Hook-and-loop fasteners exhibit sustainability potential due to their reusability; however, material-level recycling remains challenging, primarily because they often combine two different polymers (e.g., PA66 and PET). As a result, sustainable production strategies emphasize material uniformity and ease of disassembly. In sustainable design, hook-and-loop fastener solutions that are based on recycled polymers, compatible with mono-material systems, free from chemical coatings, and equipped with removable mounting mechanisms represent the most environmentally favorable approaches for both production and end-of-life management.

11. CORD END & STOPPER

Cord ends and drawstring accessories (cord stoppers, cord locks) are functional textile accessories used to secure the ends of cords, strings, or elastics in garments, prevent fraying, and enable adjustability. While enhancing ease of use and wearer comfort, these components also serve as aesthetic complements to garment design.

Cord ends are attached to the terminal parts of cords to prevent unraveling, fiber opening, and wear, whereas drawstring accessories allow users to easily adjust cord length. Most drawstring systems incorporate spring-loaded or locking mechanisms to maintain the desired tension and position. Cord ends and drawstring accessories are widely used in sportswear and activewear (e.g., tracksuits and sweatshirts), outerwear (e.g., jackets, hooded garments, and rainwear), outdoor and technical textiles, childrenswear, bags, and various accessory products. As such, they function as complementary components that enhance garment ergonomics and functionality.

Figure 21. Cord end & stopper (https://www.etsy.com/nz/listing/1179097278/metal-cord-ends-5mm-hole-silver-gold, https://www.raystitch.co.uk/products/plastic-cord-ends-4mm-navy-set-of-2?srsltid=AfmBOoryQC5V2cerqONsp2Y33wMQNUXXnRE9xVkxcsFz2dIjIgsgM8zQ, https://www.amazon.com/YaHoGa-Drawstring-Shoelaces-Clothing-Backpack/dp/B07R7FM5Q5?th=1)

The primary materials used in the production of cord ends and drawstring accessories include:

- Plastic-based materials: polypropylene (PP), polyamide (PA), polyacetal (POM)
- Metals: aluminum, brass, steel (particularly for decorative cord ends)
- Silicones and elastomers: used in applications requiring flexible and non-slip surfaces
- Bio-based and recycled materials: rPET, bio-PA, bio-POM

Metal cord ends are typically selected for aesthetic purposes, whereas plastic- and elastomer-based drawstring accessories are preferred due to their lightweight characteristics and cost advantages.

Cord ends and drawstring accessories constitute small yet critical components that must be separated during textile recycling. Because they are often produced from materials different from the base fabric, allowing these accessories to enter the recycling stream without prior separation may lead to fiber contamination, increase the risk of damage to mechanical shredding equipment, and negatively affect the homogeneity of recovered fibers. Therefore, the removal of these accessories from garments prior to recycling is generally recommended.

Manual Separation: In the most common manual removal practice, cords and strings are cut and separated together with the accessory, while plastic or metal cord ends are removed by hand or using pliers. This approach is particularly preferred in small-scale recycling facilities and during pre-sorting stages. Although it provides high separation accuracy, its labor-intensive nature limits its applicability in large-volume waste streams.

Mechanical Separation: In industrial recycling lines, metal cord ends can be partially detected and removed using magnetic separators. Plastic drawstring accessories, on the other hand, are separated after mechanical shredding through sieving and air separation systems. However, due to the small size of these accessories and the similarity between their polymer densities and those of base fabrics, these methods generally yield limited separation efficiency in practice.

Recovery and Disposal: Separated accessories are directed to different end-of-life pathways based on material composition. Metal-containing components are routed to metal recycling streams, while plastic-based components particularly those composed of a single polymer may be processed through mechanical plastic recycling. Mixed-material or spring-loaded drawstring accessories are most often directed to energy recovery processes.

Sustainability-Oriented Approaches: To reduce the environmental impacts of cord ends and drawstring accessories in the textile sector, several sustainability-driven strategies have emerged. These include mono-material designs in which the accessory is produced from the same polymer as the cord and base fabric; the use of recycled raw materials such as rPET or recycled aluminum; detachable design approaches that enable easy separation through screw- or clip-based systems; and the development of bio-based alternatives derived from materials such as bio-PA or PLA.

12. BEAD, SEQUIN AND METAL EMBELLISHMENT

Beads, sequins, and metal embellishments are decorative textile accessories used to enhance the aesthetic value of garments, increase visual appeal, and create design differentiation. Rather than contributing to the structural functionality of a garment, these embellishments are primarily regarded as complementary elements that strengthen visual identity and fashion perception.

Beads are typically designed as small components in round or geometric forms, while sequins are flat, thin decorative elements, often featuring light-reflective surfaces. Metal embellishments are produced in embossed, engraved, or pressed forms and are fixed onto the garment surface.

Figure 22. Decorative sequins (https://kumasburada.com.tr/urun/janjanli-payet-kumas-2/?srsltid=AfmBOoowVf5Fzlba6Tz9ovktDi5BPL-felSFbLditwZ7JaiuPCIHBd2W)

Figure 23. Embellished fabric (https://kumasburada.com.tr/urun/tas-islemeli-uc-boyutlu-dantel-kumas-bebe-mavisi/?srsltid=AfmBOoqLJwnav3fgbtS6tNxK29wsDltlGW8tVy0AzMpXC5YqIiOQAH20)

Beads, sequins, and metal embellishments are widely used particularly in:

- women's outerwear and eveningwear,
- fashion and haute couture designs,
- children's clothing (for decorative purposes),
- stage costumes and special design garments, and
- accessories and complementary products.

These decorative elements are generally applied to garments through embroidery, hand stitching, adhesive bonding, or riveting techniques. The main materials used in the production of beads, sequins, and metal embellishments include:

- Plastic-based materials: acrylic, PVC, polystyrene
- Glass beads: silicate-based materials offering high brilliance and durability
- Metal embellishments: brass, aluminum, zinc alloys, steel
- Natural and semi-natural materials: wood, mother-of-pearl, ceramics
- Recycled and bio-based alternatives: recycled glass, recycled metals, cellulose-based bioplastics.

While plastic- and metal-based embellishments offer advantages such as low cost and durability, their multi-material and coated structures pose significant challenges for recycling. Beads, sequins, and metal embellishments are among the accessories with the highest contamination risk in textile recycling. The main reasons for this include their production from materials different from the base fabric, their large quantity and small size, and their fixation to garments through stitching, adhesives, or riveting.

When these embellishments enter the recycling stream without prior separation, they negatively affect both process efficiency and output quality by causing a substantial reduction in fiber quality. They may also lead to abrasion, damage, or malfunction of mechanical shredding and opening equipment. As a result, the structural integrity and homogeneity of the recovered fibers are compromised, lowering the quality of secondary raw materials.

Manual Separation: Manual removal, the most common and effective method, involves separating beads and sequins from stitching lines using scissors or seam rippers, and removing metal embellishments with pliers or cutting tools. Although this approach is preferred for high-quality garments or products with reuse potential and provides high separation accuracy, it entails significant economic limitations due to intensive labor requirements and high time costs.

Mechanical and Magnetic Separation: In industrial recycling facilities, metal embellishments can be partially separated using magnetic separators, while plastic and glass beads are removed after mechanical shredding through sieving systems and density-based separation techniques. However, due to the small particle size and similar material densities, these methods offer limited separation efficiency in practice.

Thermal and Chemical Applications: Heat-assisted methods may be applied to separate embellishments fixed with adhesives, and plastic-based beads and sequins may, in some cases, be directed to energy recovery processes. Chemical separation approaches, however, remain largely confined to research and pilot-scale applications at present.

Recovery and Disposal: Separated embellishments are directed to different end-of-life pathways depending on their material composition: metal-based components enter metal recycling streams, glass-based elements are routed to glass recycling systems, while plastic or composite structures are mostly sent to energy recovery processes or controlled disposal methods.

Sustainability-Oriented Approaches: Sustainability strategies aimed at reducing the environmental impacts of beads, sequins, and metal embellishments emphasize the adoption of design for disassembly principles, the preference for mono-material or reduced-component decorative elements, the use of recycled glass and metal inputs, and the development and implementation of bio-based and cellulose-derived decorative alternatives.

13. CONCLUSIONS AND GENERAL EVALUATION

This study demonstrates that achieving sustainability and circular economy targets in the textile and apparel sector requires a fundamental re-evaluation of the role of accessories. Sustainability approaches in the literature are predominantly addressed through fabrics, fiber types, and production technologies; however, it is evident that when accessories such as buttons, zippers, rivets, snaps, labels, hook-and-loop fasteners, and similar components are overlooked, a truly holistic impact cannot be achieved. The examined cases indicate that accessories create significant technical and operational barriers in recycling processes due to their material diversity, assembly methods, and strong structural integration with garments.

The manual, mechanical, magnetic, thermal, and optical separation methods discussed within the scope of this study reveal that current recycling infrastructures have not yet fully resolved accessory-related challenges. In particular, the permanent integration of metal- and plastic-based accessories into garment structures often necessitates cutting the fabric prior to recycling, resulting in both material losses and reduced recycling efficiency. In this context, it becomes clear that efficiency losses observed during recycling processes stem not only from technological limitations but largely from decisions made at the design stage.

This study highlights that the application of the Design for Disassembly (DfD) approach specifically to textile accessories offers an effective and feasible strategy for addressing these challenges. Accessory solutions that are mono-material, easily detachable, coating-free, and produced from recycled raw materials enhance material compatibility in recycling processes, shorten separation times, and enable textile waste to be more effectively integrated into fiber-to-fiber recycling loops. The industrial examples examined demonstrate that detachable button and rivet systems, as well as modular zipper designs, significantly reduce fabric loss while increasing overall recycling rates.

In conclusion, in order to achieve sustainability goals within the textile sector, accessories must no longer be regarded merely as aesthetic or supplementary elements, but rather as fundamental engineering and design components that define a product’s life cycle. The material composition, assembly methods, and disassembly characteristics of accessories emerge as critical evaluation criteria, on par with fabrics themselves.

14. FUTURE PERSPECTIVES

The future of accessory-oriented sustainability approaches in the textile sector requires an integrated transformation across the axes of design, production, recycling, and digitalization. In the coming period, the redesign of accessories as mono-material and modular systems is expected to become one of the key strategies for improving the efficiency of recycling infrastructures. In particular, designing critical accessories such as zippers, buttons, and rivets to be removable without damaging the garment will support the scalability of circular textile systems.

With the increasing adoption of Digital Product Passport (DPP) applications, it is anticipated that information on the material composition of accessories, disassembly instructions, and recycling scenarios will become digitally traceable. This development will enhance the accuracy of automated separation systems in recycling facilities while simultaneously guiding consumers toward more informed product use and disposal behaviors. The transition from physical labels to digital information carriers offers significant potential for reducing accessory-related waste generation.

Moreover, advances in artificial intelligence–based visual recognition systems, NIR sensors, and robotic disassembly technologies are expected to make accessory separation processes faster and more cost-effective. However, the effective operation of these technologies requires accessories to be designed from the outset in alignment with such systems. Consequently, future sustainable textile products will rely not only on advanced recycling technologies but also on product architectures explicitly designed for recycling.

From an academic and industrial research perspective, there is a growing need for studies focusing on life cycle assessments (LCA), material flow analyses, and the quantitative evaluation of disassembly performance for textile accessories. Such studies will provide numerical evidence of the environmental impacts of accessory-oriented design decisions, thereby offering valuable guidance for policymakers, manufacturers, and designers.

Ultimately, the transition to a circular economy in the textile sector necessitates a rethinking of accessories. Future sustainable textile systems will be built upon interdisciplinary and data-driven approaches in which detachable, traceable, and recycling-compatible accessory solutions are placed at the core of the design process.

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