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Durable Apparel in the Circular Economy: Exploring the effect of post-industrial material waste on garment lifetimes

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Abstract: A key principle within a circular fashion system is to extend garment lifetimes by increasing durability, thereby reducing consumption, and improving resource efficiency (Ellen MacArthur Foundation, 2017; Bocken et al, 2016). Durability is now an established concept within sustainable apparel, with research informing best practice principles for design and product development (Cooper et al, 2014). Sustainable design should be a strategic process, incorporating the integrated systems of manufacturing, distribution, retail, and consumption (Ceschin and Gaziulusoy, 2016), seeking to minimise waste and other environmental impacts at all stages of the product lifecycle (Vinhod et al, 2011). Nonetheless, problems occurring during the manufacture and supply of apparel designed to be durable can lead to material waste generation, thereby undermining any potential improvements in resource efficiency (Claxton et al, 2017). This paper uses a qualitative multiple case study approach to explore retailer and supplier perspectives of the nature and management of post-industrial material waste problems of durable apparel, and assess their effect on garment durability claims. The findings demonstrate that the garment lifetime can be compromised by material waste arising from inefficiencies and a lack of transparency within production process management. The paper concludes that retailers aiming to demonstrate circularity by producing durable apparel should review the relationship between durability and sustainability performance outcomes, where waste is viewed as an environmental, as well as a financial impact. Problems should be effectively managed to prevent material waste and a reduction in garment lifetimes, and solutions must be holistically applied, ensuring that all stages of the supply chain are included.

Introduction

Durable apparel design seeks to reduce the need for consumers to replace garments that have failed prematurely, thereby reducing production volumes and the associated post-consumer waste (Ellen MacArthur Foundation, 2017). Indeed, extending the active life of 50% of UK clothing by nine months would reduce the annual carbon, water, and waste footprints by an estimated 20-30% each (WRAP 2017). Circular textiles and apparel literature tends to depict the lifecycle of a durable garment in a singular dimension, moving through potential cycles of manufacture, use and ownership within circular business models or CBMs (Pal et al, 2019). However material waste in the form of yarn, fabric and garments can be created at every stage of the upstream supply chain during manufacture, and also during the storage, transport and retail stages of the product lifecycle where garments may be found to be faulty, and customer returns or poor sales can lead to the disposal of wearable garments (Reverse Resources, 2017). The resource efficiency benefits claimed for durable apparel may therefore be undermined and the waste unaccounted for in apparel retailers' sustainability reporting (Akter et al, 2022). This study investigates the factors leading to post-industrial material waste within the apparel supply chain. By using a qualitative approach, the research aims to demonstrates a deeper understanding of the potential commercial and operational challenges of managing and addressing potential waste problems that could undermine a circular apparel model based on durability.

Literature Review

Durability as a circular design principle.

Improving apparel durability has been proposed a sustainable design approach as garments that last longer can theoretically reduce overall consumption, the associated environmental impacts of production, and post-consumer

waste (Laitala et al., 2015). Advocates of the circular economy propose that the entire garment lifecycle should be considered, identifying opportunities to improve resource efficiency, reduce waste, and minimise damage to the environment at each stage (Ellen MacArthur Foundation, 2017). In the circular model, durable apparel is depicted within a system of multiple cycles of production and consumption, demonstrating its potential to retain and create value across different CBMs such as resale and rental (Pal et al, 2019). Physical durability can be enhanced by using fabrics and sewing methods that are more hardwearing, reducing the risk of garment failure (Cooper and Claxton, 2022), whereas emotional durability refers to the consumer's attachment to, and enjoyment of wearing the product that keeps it in use for longer (Chapman, 2015). Consumers already demand durable apparel in functional garments and classic wardrobe staples such as jeans and basic t-shirts (Fisher et al, 2008) and are more likely to wear a garment for longer if it continues to fit them well, feels comfortable and looks good; therefore good practice in emotionally durable design for classic apparel tends to incorporate ongoing improvement of body fit, overall design aesthetics and comfort (Cooper et al, 2016).

Factors leading to post-industrial apparel waste

Apparel retailers normally outsource manufacturing to external suppliers, passing over control for volume production once a new style has been developed and approved (Shen and Chen, 2018). Factories follow routine quality assurance (QA) procedures to ensure that garments meet the specified aesthetic, physical performance and safety standards established at the design stage, and quality control (QC) practices monitor the consistency of the product as it progresses through production (Keiser and Garner, 2017). Textile and apparel manufacturers can apply risk assessment and lean manufacturing principles to optimize production efficiencies and reduce costs, as well as contribute towards sustainability by minimising waste However, materials, components and garments tested and found to be non-compliant may be rejected and potentially wasted if the problem cannot be rectified (Cooper et al, 2016; Vinodh et al, 2011). Furthermore, the transparency of post-industrial waste generation can be obscured by operational inefficiencies within globally fragmented supply chains, making it more difficult to share data and knowledge between the buying company and suppliers (Aage and Belussi, 2008). Influence over upstream suppliers can be weak, sometimes resulting in sub-standard materials and garments being hidden (for example in the practice of non-disclosed production sub-contracting), and the requirements for increased speed and flexibility of supply can lead to inadequate product risk assessment (Shen and Chen, 2018). As a result, clothing retailers and suppliers can encounter problems both during and after production that create waste and / or shorten the overall product lifetime (Claxton et al, 2017). Examples include defective materials and garments caused by poor process and inventory management; fibre, yarn and fabric waste generated during manufacturing; and surplus materials or dead stock caused by overproduction, late deliveries and inaccurate demand forecasting (see figure 1). Current post-industrial waste volumes are significant, with up to 25%-30% of the original fibre estimated as being wasted throughout the apparel supply chain, and less than 1% of raw materials being fully recycled as a closed loop process (Reverse Resources, 2017).

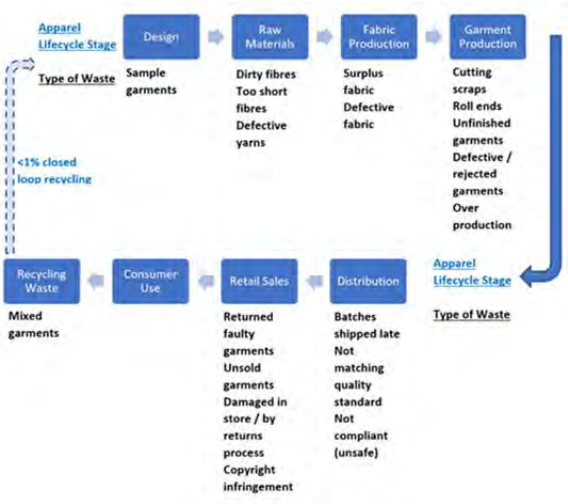

Figure 1. Simplified apparel supply chain model with examples of material waste at each stage. Adapted from Reverse Resources, 2017.

The effective resolution of waste issues requires negotiation between buyers and suppliers to establish responsibility and agree action to be taken (Cooper et al, 2016). As waste avoidance has a financial benefit, cost

recovery is commonly prioritised in resolving waste problems rather than sustainability; this includes applying financial penalties to suppliers of faulty goods (Shen and Chen, 2018) and finding other markets or applications for substandard or surplus materials and products (Akter, 2022). However, the overall waste generated by producing a specific apparel style in volume within a globally widespread supply chain is difficult to measure as the retailer may only be involved in resolving issues created in the first or second tier of supply representing garment and fabric production (Reverse Resources, 2017). Curwen et al (2012) propose that a company mandate for sustainability, shared values between retailers and suppliers, and more effective and transparent knowledge exchange is needed to address these challenges, however the greater power of the retailer in supplier relations can lead to a lack of trust and transparency on both sides (Talay et al., 2022). To date, initiatives to address post-industrial waste have been limited by a lack of transparent data, and the low priority of waste within sustainability reporting, meaning that the journey and eventual destination of wasted material or product is often unknown (Reverse Resources, 2017).

Apparel durability and waste within the circular model

Apparel retailers are now piloting CBMs to assess the economic and practical viability at scale (BSR, 2021), although infrastructural and cultural barriers limit consumer engagement (Camacho-Otero et.al., 2018). Nonetheless, many retailers have started to incorporate circular principles such as durability and recyclability into apparel design to prepare for a future circular model that may be more formally regulated through legislation (Gueye, 2021; European Commission, 2022). Measuring a product's environmental impacts can inform circular design approaches, and lifecycle analysis (LCA) frameworks can be used to map, measure, and address the associated water use, greenhouse gas emissions, chemical emissions, and energy consumption

(Munasinghe et al., 2021). However, apparel durability can be measured through physical testing regimes, but is not commonly incorporated into LCA frameworks that predict environmental impacts at the design stage (Kozar and Hiller-Connell, 2015). Moreover, even if a product has been designed to be durable, the associated post-industrial and post-consumer waste is difficult to measure as retailers are not in control of the manufacturing or consumer use stages of the product lifecycle (Laitala et al, 2018). It can therefore be argued that the overall durability of apparel products can be undermined when post-industrial waste is generated during production, distribution or retail, and that it is difficult to predict or assess this through LCA at the design stage (Claxton et al, 2017).

Research Design and Methods

This paper goes on to investigate the following research questions:

1. What are the examples and causes of post-industrial waste are created in the supply chain of durable apparel?
2. How do buyers and suppliers at each stage of the supply chain attribute responsibility, find solutions and take action?
3. What are the opportunities for developing more effective practices to reduce waste that could support sustainability and circularity claims related to durable apparel?

A multiple case study approach as proposed by Yin (2018) was employed where participants were able to describe and address the specific issue and research questions. Qualitative semi-structured interviews were undertaken with seven industry experts representing five apparel companies to explore first-hand experiences of the management and mitigation of post-industrial waste problems and premature garment failure. The case companies were UK based apparel retailers and a first-tier garment supplier. Expert participants in apparel product development and supply chain relations provided information relevant to the research questions and aims of the study, having been identified by purposive selection (Maxwell 2012). Retailers A B and C are private label brands of differing size, market level and customer focus. Company D is a SME manufacturer brand with a semi-vertical supply chain. All the companies, including garment supplier E have globally diverse supply chains. Each company has a stated commitment to sustainability that could influence design strategies, although the range of initiatives varied, with only one company (B) explicitly linking sustainability to circularity.

The interviews explored eight examples of classic apparel styles designed with a 'best practice' approach to garment durability that had all failed to meet the required quality or compliance standards of the retailer resulting in post-industrial waste. Due to confidentiality requirements, Retailer B discussed a range of general examples rather than specific products. A process of thematic analysis was used to organise and code the data into categories aligned with the research questions. The case companies, research participants and products discussed are listed in Table 1.

Company	Participant	Products Discussed
A: Large UK high street clothing retailer	A1 Technical Manager multi product	Men's formal trousers Boy's formal trousers
B: Large online clothing retailer	B1 Sustainability Manager	General discussion of product problems that can occur resulting in material waste
C: Medium size online retailer	C1 Technical Manager C2 Senior Technologist (Knitted Product) C3 Senior Technologist (Accessories)	Women's jersey leggings
		Women's printed silk scarf
D: Small cashmere brand / manufacturer	D1 Technical Director	Women's cashmere sweater
E: first tier supplier to a large UK high street retailer	E1 Technical Executive	Women's cotton sweater
		Women's lambswool sweater
		Women's acrylic sweater

Table 1. List of case companoes, research participants and products discussed.

Analysis and Discussion of Research Findings

The research findings derived from the first two objectives explored the factors leading to post-industrial waste or premature garment failure, and how buyers and suppliers within the supply chain assess, manage, and mitigate waste problems (see Table 2 for a full analysis). In response to the third objective, participants discussed how waste was accounted for within their business, potential improvements to mitigate waste impacts and increase transparency, and ways of integrating this with sustainability strategy and reporting.

Classification and causes of problems leading to apparel waste

All eight garments were considered classic styles and the participants confirmed that durable design principles are commonly used within the new product development process for classic apparel using 'best practice' QA methods in line with Cooper et al's Clothing Longevity Protocol (2014). All had failed to meet the required quality or compliance standards during production and had resulted in wasted garments, fabric, or yarn. Poor production process control and inadequate risk assessment of changes to product specifications and distribution routes were found to be the main causes of waste, rather than errors in product design and specification. Four garments were affected by inadequate control of quality or manufacturing procedures resulting in inconsistent garment sizing, fabric shrinkage, fabric faults and excessive pilling; two garments were found to be non-compliant to safety regulations and deemed unsafe for wear; and the remaining two were affected by changes to the product specification or factors during transit which caused unforeseen damage to the garments.

Management of waste problems: finding solutions and taking action

Influence of supply chain stage where problem identified on waste implications:

The different examples discussed generated waste at the manufacturing, distribution and retail sales stages of the garment lifecycle, in line with Reverse Resources' model (2017). All participants discussed the importance of finding problems early in order to reduce the scale of potential waste and lost sales. For instance, supplier E found problems early at pilot manufacturing stage for two sweater styles where a new yarn supplier or a modified yarn was being assessed. Although this caused some waste, the problems were discussed with the retail customer and resolved for the majority of the order. If problems are found following production, for instance in the retailer's warehouse, retail outlets or by customers, the opportunity to address them is more limited; the focus is on salvaging sales, learning lessons for future orders and disposing of affected stock through nominated routes. Retailer C's problem with inconsistent sizing on jersey leggings, and

Product	Description of problem	Supply chain stage	Reason and responsibility	Action taken	Waste handling
Retailer A Men's and Boy's formal trousers (2 styles, same fabric).	**Safety non-compliance:** pocket lining dyed with harmful chemicals (part order).	**Retailer's stores:** due diligence testing by retailer from products in-store.	**Garment supplier.** Dyehouse sub-contracted part of the order for pocket dyeing to another dyehouse without the retailer's knowledge.	Destruction of entire stock due to inability to identify affected garments. Supplier was fined and no further business placed.	Stock was destroyed (incinerated).
Retailer C Women's jersey leggings.	**Non-conformance of sizing:** variation due to poor quality control in pressing / cutting.	**Retailer's UK warehouse:** quality inspection of delivered stock.	**Garment Supplier**. The problem pointed to poor production control. Exact reason was not discovered due to inadequate investigation.	100% inspection of stock resulting in high rejection rate and insufficient stock availability. Entire order was returned to the supplier.	Not known what the leggings supplier did with the rejected stock.
Retailer C Printed silk scarf (continuity line with seasonal print).	**Product damage:** new adhesive care label left adhesive residue on the product.	**Consumer:** returns / complaints after handling / wearing the product.	**Difficult to assign responsibility.** Due to either inadequate assessment of new label, or change in label quality.	Scarves were reprocessed to remove adhesive. Problem persisted so they were withdrawn from sale.	Retailer sold off some of the scarf stock at public sales and remainder sent to charity.
Brand / manufacturer D Women's cashmere sweater.	**Non-conformance to fabric performance:** excessive pilling.	**Consumer:** returns / complaints after wearing the product.	**Yarn spinner**: Insufficient control of spinning process leading to brittle yarn.	Garments withdrawn from sale. The yarn was tested to identify the problem. Meanwhile, a new anti-pill finish was applied in production.	The returned faulty cashmere sweaters were donated to charity.
Supplier E Women's cotton sweater.	**Product damage:** mould found on cotton garments after shipping.	**Supplier's UK warehouse**: quality inspection of delivered stock.	**Garment supplier.** Garments became damp during storage in Bangladesh. The mould developed over the 4-6 week journey to the UK.	Re-processing of affected stock to remove mould. Humidity control system was set up in Bangladesh warehouse.	Destruction of part of the order (3,000 pieces) where mould could not be removed.
Supplier E Women's lambswool sweater.	**Non-conformance to fabric performance**: dimensional stability tests failed on pilot order.	**Supplier's Bangladesh factory**: factory QC procedures performance testing.	**Yarn spinner.** Production process control issue. Problem not present at NPD stage.	Entire order cancelled. Left-over yarn and garments were returned to the spinner who was charged for the loss.	Not known what the spinner did with the yarn and garments.
Supplier E Piece dyed women's acrylic sweater.	**Non-conformance to fabric appearance**: uneven dyeing observed when trialling a new yarn supplier.	**Supplier's Bangladesh factory:** factory QC procedures / visual assessment.	**Yarn spinner.** Production process control issue. Problem not present at NPD stage.	100% inspection of stock resulting in high rejection rate. Left-over yarn and garments returned to the spinner who was charged for the loss.	Not known what the spinner did with the yarn and garments.

Table 2. Analysis of case company apparel waste problems.

the mould affecting supplier E's cotton sweater were found on completed production orders during quality checks in UK based warehouses, and the scale of each problem was too widespread to be able to salvage a commercial quantity of acceptable product. Retailer A's men's and boy's formal trousers were found to have banned chemicals in the pocket linings following due diligence testing carried out on product taken from retail stores. Retailer D's cashmere sweater and Retailer C's silk scarf developed problems during initial use causing premature product failure and resulting in customer returns. Products were withdrawn from sale until a solution could be found.

Approaches to waste handling:

The case companies investigated the eight apparel styles to identify the nature, cause, and implications of the waste problem. Retailers must follow legislation relating to safety non-compliance, so company A's men's and boy's formal trousers containing harmful chemicals meant that the garments could not be sold and were destroyed by incineration. Disposal routes for the other six products shown in Table 2 were varied, and included the following: one style where part of the order was destroyed due to garments being spoiled by mould; three styles where faulty yarn, fabric or garments were returned to the supplier deemed to be responsible; and faulty garments from two styles were disposed of via sample sales and / or charity donation. Where garments or fabrics were found to be unusable through being defective, any rejected stock was seen as the responsibility of the producer and action would be taken to recover costs which included the imposition of fines for any actions contravening contractual agreements. All the retailers interviewed had a range of options and conditions for dealing with rejected stock that depended on the size and nature of the problem, although there was considerable variation in approach. Retailer A had the most formal contractual requirements for waste handling of defective garments; suppliers could elect to take the stock back, de-brand it and sell on to a different market during a later season, have it sold as 'seconds' through nominated UK factory outlets or donated to charity partners. However, in the cases of retailer C and supplier E, the eventual disposal route of defective fabric and / or garments returned to suppliers was unknown due to having no waste tracing policy in place.

Opportunities for reducing material waste problems

Improving communication, trust, and transparency:

Interviewee C2 stated that it was difficult to allocate time and resources to investigate problems with its jersey leggings, thus it remained unresolved, and the opportunities to learn lessons and improve procedures were limited. This concurs with Aage and Belussi's (2008) assertion that geographically distant global sourcing locations can prevent the sharing of knowledge and data between buyers and suppliers. Participants agreed that resolving problems originating beyond the first tier garment supplier is even more challenging as retailers have little influence on, and knowledge of processes further upstream. However, interviewee A emphasised that resolving the problem on their two trouser styles was essential as product safety is a legal, rather than a voluntary requirement, thus they were prepared to invest time and resources to visit the garment and fabric suppliers, and the dyehouse in China. All participants agreed that trust and knowledge sharing between suppliers and buyers were critical in identifying potential waste problems at an early stage and learning lessons to avoid them. That said, the findings demonstrated that retailers perceived a lack of competence and / or transparency on the part of suppliers, and the most serious waste problems contravened contractual agreements, such as retailer A's supplier's use of unauthorised sub-contracting. On the other hand, supplier E stated that it can be difficult to decide when and how to communicate a problem to the retail customer as transparency could lead to a lack of confidence and the risk of order cancellations.

Improving waste management approaches and systems:

Participants agreed that supply chain waste transparency between buying companies and their suppliers is insufficient to allow the development of circular approaches to waste handling, although the larger retailers had the most ambitious and formal approaches in place. Retailer B was developing a protocol for fabric or garment stock that had to be written off, and setting up a tracker to trace garments and any associated waste throughout the supply chain. Interviewee A1 stated that careful selection of waste handling partners was

imperative, and that focusing on partners with the best environmental compliance programmes should be prioritised over seeking the best price. Participants also discussed potential new CBMs such as re-manufacture of dead stock, and reverse supply chain initiatives within upstream processes as having the potential to increase resource efficiency, repurpose waste and achieve financial benefit as proposed by Reverse Resources (2017). Interviewee B1 suggested that these approaches are likely to gain more prominence as companies respond to multi-stakeholder sustainability / circularity initiatives such as WRAP's Textiles 2030 (WRAP, 2022). Retailer A had already set up an in-house team to re-design and manufacture new products from pre-consumer waste garments and fabric, selling through their outlet stores. Interviewee B1 suggested that this approach could also be outsourced to specialist re-processing companies, but would be difficult for value retailers as the cost of reprocessing could be higher than the original garment cost.

Incorporating post-industrial waste into sustainability reporting:

All interviewees confirmed that apparel durability was important to their brand identity and quality level, but waste created during the production and distribution of the example garments was accounted for in financial terms only, via charges covered by contractual agreements and in lost sales. Apart from retailer B who had created a collection designed with circularity principles, durability was not seen explicitly as a sustainability proposition. Participants agreed that waste levels above industry norms created by durable apparel production and supply would undermine any sustainability or circularity claims relating to extending garment lifetimes. However, it was evident from the examples discussed that waste was not fully traceable where defective fabric and garments were returned to suppliers, meaning that data to inform accurate LCA was largely unavailable. Retailer B was the only company using LCA to assess apparel sustainability, but in a very basic way to inform fibre and fabric selection at the design stage. Participant B1 stated that transparent accounting for post-industrial material waste impacts may become important in the near future due to proposed legislation on waste reduction and increasing resource efficiency, responding to initiatives such as the EU Strategy for Sustainable and Circular Textiles (European Commission, 2022). It was also suggested that including waste measurement and prevention within business sustainability strategies and reporting could improve transparency and drive more effective lean management practice and risk assessment within the supply chain as proposed by Vinhod et al. (2017), thereby supporting the move to a circular approach.

Conclusion

Evaluating apparel durability as a circular approach has identified several issues that need to be overcome to support sustainability claims. The research demonstrates that durability needs to be measured at an individual product level to support circular business models, but that where durable apparel is proposed as a circular approach, it should not be solely assessed in the single dimension of LCA at the design stage. Garment production and supply in volume should maximise material resource efficiency and minimise waste created due to unforeseen or poorly managed commercial or manufacturing problems, and waste should be viewed as an environmental, as well as a financial impact. Solutions to address waste and support circularity should be holistically applied, crossing company boundaries and ensuring that all stages of the supply chain are included. This is necessary to address the fragmented nature of apparel supply chains, and the resultant lack of transparency and innovative solutions in managing and preventing post-industrial material waste to achieve credible sustainability improvements. A limitation of the research is its focus on UK based fashion businesses. The issues discussed could be investigated further within other product sectors and in global retail markets.

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