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DEVELOPING A SUSTAINABLE DESIGN TOOLKIT FOR WOOL PRODUCTS

DESENVOLVER UM KIT DE FERRAMENTAS DE DESIGN SUSTENTÁVEL PARA PRODUTOS DE LÃ

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Abstract
This study develops a sustainable design toolkit for the wool industry to provide a systematic framework that reduces the environmental impact of wool products. Based on lifecycle thinking and circular design principles, the framework integrates global sustainability standards with industry practices across the product lifecycle, from material sourcing to end-of-life management. Using qualitative analysis, the toolkit is structured into four modules: material selection, design guidelines, production practices, and end-of-life management. Case studies and literature review were conducted to capture industry needs and synthesize existing research. The findings highlight a strong demand for the toolkit, with positive feedback from academia and supply chain partners. The toolkit consolidates fragmented standards, offering a practical and adaptable resource that will continue to evolve. This research contributes both theoretically and practically by equipping practitioners with tools to strengthen the wool industry and support the transition of the fashion and textile sector toward sustainability and circularity. It fills a gap in sustainable wool design by providing a unified framework that connects research, standards, and best practices.

Keywords: Sustainable Design Toolkit. Sustainability. Fashion Industry. Textile. Wool. Education.

Resumo
Este estudo desenvolve um conjunto de ferramentas de design sustentável para a indústria de lã, a fim de fornecer uma estrutura sistemática que reduza o impacto ambiental dos produtos de lã. Com base no pensamento do ciclo de vida e nos princípios do design circular, o conjunto integra padrões globais de sustentabilidade com as práticas da indústria em todo o ciclo de vida do produto, desde a obtenção de materiais até a gestão do fim da vida útil. Utilizando análise qualitativa, o conjunto de ferramentas é estruturado em quatro módulos: seleção de materiais, diretrizes de design, práticas de produção e gestão do fim da vida útil. Estudos de caso e revisão bibliográfica foram conduzidos para captar as necessidades da indústria e sintetizar as pesquisas existentes. Os resultados destacam uma forte demanda pelo conjunto de ferramentas, com feedback positivo da academia e de parceiros da cadeia de suprimentos. O conjunto de ferramentas consolida padrões fragmentados, oferecendo um recurso prático e adaptável que continuará a evoluir. Esta pesquisa contribui teórica e praticamente, equipando os profissionais com ferramentas para fortalecer a indústria de lã e apoiar a transição do setor da moda e têxtil em direção à sustentabilidade e à circularidade. Ele preenche uma lacuna no design de lã sustentável, fornecendo uma estrutura unificada que conecta pesquisa, padrões e melhores práticas.

Palavras-chave: *Conjunto de ferramentas de Design Sustentável. Sustentabilidade. Indústria da Moda. Têxtil. Lã. Educação.*

1 INTRODUCTION

1.1 Background

1.1.1 Global environmental impact of fashion and textile industry

The global fashion and textile industry is one of the largest the pollution and influence to the environment, accounting for approximately 10% of global carbon emissions and 20% of global wastewater production (Ellen MacArthur Foundation, 2017). Fashion industry heavily relies on resource-intensive processes, including water usage, chemical treatments, and energy consumption. For example, during the production procedure of one cotton T-shirt requires approximately 2,700 liters of water, which equivalent to a person's drinking water for 2.5 years (WWF, 2020).

Furthermore, the synthetic fibers, such as polyester and nylon are widely used, which has led to a surge in microplastics in aquatic ecosystems, posing significant threats to marine biodiversity and human health. It is estimated that around 35% of microplastics in the ocean originate from washing synthetic textiles (Boucher & Friot, 2017). With a growing global waste and increasing demand for fast fashion, the environmental pressures from the textile are projected to rise. Designers, researchers and educators are trying to find the substantial solutions to make a better world.

1.1.2 Importance of sustainable design in modern society

To address the environmental challenges caused by industrial activities, including fashion and textiles. Sustainable design has been the important and only solution. Rooted in the principles of environmental responsibility, resource efficiency, and social equity, sustainable design aims to minimize ecological footprints while ensuring product functionality and aesthetic appeal (McDonough & Braungart, 2002).

Recent years, governments, industries, and consumers are increasingly recognizing the value of sustainable design. There are many regulatory frameworks have been drafted and pulished, such as the European Union's Green Deal and Circular Economy Action Plan, are supporting sustainable practices in product design and manufacturing. At the same time, consumers are concerning ethical consumption, with

surveys indicating that 73% of millennials are willing to spend more on sustainable brands (Nielsen, 2019). These trends indicate the necessary of embedding sustainability into the core of design practices to meet contemporary environmental and social expectations.

1.1.3 Sustainable characteristics of wool

Wool is widely recognized to be a sustainable material for its superior sustainable characteristics, making it an important material for environmentally conscious design. Beyond its basic renewable and biodegradable nature, wool also possesses several unique characteristics that contribute to a more sustainable fashion and textile industry.

a) Biodegradability and Minimal Environmental Impact

Wool is a 100% biodegradable natural fiber. Wool decomposes within a few years in soil when discarded, while releasing valuable nutrients such as nitrogen, sulfur, and magnesium, which enhance soil fertility (IWTO, 2021). Different from the synthetic fibers, wool does not cause microplastic pollution during washing or disposal, which ensuring minimal long-term environmental impact.

b) Recyclability and Reusability

Wool can be recycled and reused more easier than other fibers. The recycle and reuse action can reduce the demand for virgin material and promoting circularity in the textile industry. For instance:

Recycled Wool Yarn: Existing wool garments and leftover wool yarns can be unraveled and reprocessed into new yarns. These recycled yarns are then used to produce fresh woolen products without compromising quality.

Handcrafted Wool Products: There are some hand-knitted wool items, such as sweaters, scarves, and blankets, can be unraveled and the yarn reused for crafting new items. This practice not only reduces waste but also show the slow fashion principles, emphasizing craftsmanship and durability.

Existing Inventory: There are large stocks of unused wool yarns or outdated wool garments in the fashion industry can be reprocessed as raw materials. For example, out-of-date wool fibers in the factories or inventory merchandise from retailers can undergo shredding and repining processes to create recycled wool fabrics.

c) Outstanding Material Properties

Wool shows several inherent properties that make it a preferred choice for sustainable product design:

Durability: Wool fibers are naturally resilient and elastic, allowing garments to retain their shape and function for a long period. This durability can directly cause fewer replacements, thereby reducing resource consumption.

Moisture Management: Wool fibers can absorb up to 30% of their weight in moisture without feeling damp, offering superior comfort in varying climates.

Thermal Insulation: Wool's crimped fibers can trap air, providing excellent thermal insulation. This property makes wool garments suitable for multi seasons, reducing the necessary for multiple layers and energy use for heating or cooling.

Odor Resistance: Wool's natural lanolin and antibacterial properties prevent the accumulate of odor, extending the time between washes, which can save water and energy.

d) Health Benefits from Wool for Humans

Wool is not only sustainable for the planet but also beneficial for human health:

Temperature Regulation: Wool helps regulate body temperature, keeping people warm in cold weather and also cool in hot weather. This makes it particularly suitable for and beneficial to infants, the elderly, and sports people.

Skin Comfort: Contrary to the traditional perception of wool as "itchy," modern processing techniques can produce soft, fine-grade wools such as Merino, which are gentle on the skin and hypoallergenic.

Improved Sleep Quality: Studies suggest that sleeping on wool bedding or wearing wool sleepwear can improve sleep quality due to its ability to maintain an optimal microclimate around the body (Woolmark, 2019).

e) Encouraging Local Economies and Craftsmanship

Wool products play an important role in supporting local economies and preserving traditional craftsmanship. As a natural and renewable fiber, wool production can provide employment and sustains communities.

1.1.3.1 Supporting local economies

Regional economic development was promoted through contributions from the wool sector, such as job opportunities for sheep grazing, shearing, spinning, weaving, and garment manufacturing. Smallholder farmers and independent craft artisans are also benefited through demand for ethically sourced wool, enabling fair trade and sustainable living. Wool production generates thousands of jobs, from shepherding through high-fashion design, where there are strong wool industries, such as New Zealand and Scotland (The Campaign for Wool, 2021).

Furthermore, wool products produced from local wool reduce reliance on manufactured synthetic materials, promoting independent economies. With consumers choice for regionally sourced wool, the revenue generated remains within the community, boosting local businesses and strengthening rural economies (International Wool Textile Organization, 2020).

1.1.3.2 Preserving craftsmanship and heritage

Traditional wool production is closely linked with cultural heritage. Some of the traditional techniques, that have been kept alive through wool craftsmanship include hand-spinning and hand-weaving. These not only have low environmental impacts but also have the capability for producing unique and quality textiles with local flair. For example, the Harris Tweed industry in Scotland, involves a requirement that every meter of fabric is handwoven on islanders' own looms at home, with a practice that is centuries old (Harris Tweed Authority, 2022).

Furthermore, there are many wool cooperatives and artisan collectives throughout the world that strive to maintain indigenous textile practices. For instance, Andean weavers in Peru continue to use natural dyes and traditional looms to create intricate wool textiles, their cultural heritage remaining intact and honored for future generations (Smith & Jones, 2019).

Wool products are a classic case of symbiosis between cultural preservation and economic sustainability. Consumers, by buying wool products, are helping local economies as well as preserving traditional skills at one and the same time. Buying

ethically sourced, traditionally made wool products will help ensure that rural livelihoods are maintained as well as centuries-old textile traditions.

1.1.4 Current inventory situation of wool yarns and wool garments

The global wool industry, well recognized for its sustainability potential, is faced with how best to utilize existing stockpiles of garments and yarn made from wool. Utilization of these stockpiles is crucial for further growth of circular economy strategies for fashion and textiles.

a) Inventory of Wool Yarns

Wool yarns, at times produced in excess to meet variable demand, are generally stored for a long time. These yarns are, for the most part, not utilized due to a change in consumers' preferences, excess production, or seasonal fashion trends. Wool yarns are stored by manufacturers and retailers, which, if not utilized, translate into not just financial losses but also wasted sustainable materials (IWTO, 2021).

There are efforts being made to reuse excess yarns into new products. These materials are being utilized by designers and artisans for small-volume or bespoke products, such as hand-knitted garments, accessories, and homeware textiles. It minimizes wastage and aids sustainable production (Fashion Revolution, 2020). Other schemes, such as yarn donation schemes for craft communities, also redirect excess stock for creative and functional purposes.

b) Inventory of Wool Garments

In fast fashion, there is a persistent excess of clothing made from wool. The retailers keep large quantities because there is overproduction, as well as due to mismatches between production and consumer demand. Such excess items are typically reduced during sales or, with less sustainable behavior, dumped (Global Fashion Agenda, 2021).

Circular economy measures are addressing this issue through encouraging recycling and upcycling of clothing made from wool. Technologies such as shredding and respinning make unsold or second-hand clothing's wool reusable as quality yarns or fabrics (Textile Exchange, 2022). Brands and organizations are also collaborating with each other to develop take-back schemes, where consumers return old clothing made from wool for processing into new products, extending the material's lifecycle.

c) Challenges and Opportunities

The current inventory condition captures both challenges and opportunities for managing wool resources:

Challenges:

- Excess inventory occupies space and is expensive, and can also cause materials to spoil over time (WWF, 2020).
- There is a lack of effective logistics and infrastructure for sorting, processing, and collecting wool yarn and garments, which prevents large-scale recycling.

Opportunities:

- Surplus wool inventory can also be used for promoting sustainable fashion, for instance, through designer collaborations for upcycled collections (Ellen MacArthur Foundation, 2017).
- New material recycling technologies, including chemical recycling technologies, have potential for high-quality recycling of wool fibers from garments with a mixture of materials (Textile Exchange, 2022).
- Consumer campaigns that emphasize recycling and upcycling of wool can drive demand for second-life products (Global Fashion Agenda, 2021).

1.2 Problem statement

Wool is a natural and renewable fiber, which offers a more sustainable alternative to synthetic fibers. However, the industry still facing a lot challenges, including inefficient resource utilization, large amount waste generation, and the lack of standardized sustainable design practices, despite wool act well with the eco-friendly attributes.

Many wool products are produced without considering the full life cycle impact. There are some problems generated, such as: excessive dyeing chemicals, poor recyclability, and limited consumer awareness of sustainable choices. Additionally, lack of accessible guidelines to integrate sustainability principles into wool product development effectively from the aspect of designers and manufacturers.

In order to solve the urgent environment problem, the industry need a Sustainable Design Toolkit that provides structured guidelines and best practices for designing, producing, and consuming wool products in an environmentally responsible manner. This toolkit aims to assist designers, manufacturers, and consumers in making wise and

sustainable choices to enhance sustainability while maintaining the quality and functionality of wool textiles.

1.3 Objectives

This study aims to:

- Analyze the environmental impacts across the wool product lifecycle.
- Develop a comprehensive Sustainable Design Toolkit (SDT) tailored for wool products.

2 THEORETICAL FRAMEWORK

2.1 Sustainability in product design

Sustainable product design focuses on reducing environmental impacts while maximizing resource efficiency throughout the lifecycle. The core principles include in Table 1.

Table 1

3R of the Wool Industry and Products

	Introduction	Actions for example
Reduce	In the wool industry, reducing resource consumption and environmental impact.	Adopting sustainable grazing methods to prevent overgrazing and protect grassland ecosystems.
		Improving wool processing techniques to reduce the use of water, electricity, and chemicals.
		Producing more durable wool products to reduce the environmental impact of fast fashion.
Reuse	Wool is a durable material that can be used multiple times to reduce waste	High-quality wool products, such as wool coats and sweaters, can be passed down or sold second-hand.
		Old wool items can be refurbished or repaired to extend their lifespan.
		Wool scraps can be used for crafts, such as felt-making or filling materials.
Recycle	Wool can be recycled, reducing the need for new raw materials	Recycled wool from old garments can be re-spun into new yarn for the production of new products.

	Discarded wool is biodegradable and can be used in agriculture (e.g., as soil improvers) or for developing bio-based materials.
	Some brands are already using recycled wool to reduce dependency on virgin wool.

2.2 Life Cycle Assessment (LCA)

LCA is a scientific methodology to evaluate environmental impacts associated with all stages of a product's life. For wool products, key stages include:

- **Raw Material Sourcing**: Sheep grazing impacts and energy for shearing.
- **Processing**: High water usage for cleaning (scouring) and chemical use in dyeing.
- **Usage**: Energy-intensive washing and maintenance by consumers.
- End-of-Life: Limited recycling infrastructure for wool products.

Life Cycle Assessment (LCA) is a comprehensive approach to assessing the environmental impact of wool products throughout their life cycle from the perspective of the wool industry and products. LCA typically includes all stages from raw material extraction to production, use, waste and final disposal. The following are the 4 key stages and applications of LCA in the wool industry in Table 2 and Applications of LCA in Table 3.

Table 2

LCA of the Wool Industry and Products

Life Cycle Stage	Content
Raw material stage (resource collection)	Wool production: LCA first assesses the environmental impact of the wool production process, including sheep breeding, grassland management, grazing methods and water use. Overgrazing and unreasonable breeding methods can lead to land degradation, desertification and loss of ecological diversity.
	Feed and water resources: LCA also considers the feed and water use of sheep, especially in arid areas, where excessive consumption can put pressure on the environment.
Production stage (processing and manufacturing)	Wool processing: Steps such as wool washing, spinning, dyeing, weaving and finishing may involve a lot of water and chemical use. LCA assesses the energy efficiency, chemical use and wastewater discharge of these processes.
	Energy use: The type of energy used in wool processing (e.g. electricity, natural gas, etc.) has a direct impact on greenhouse gas emissions. LCA can help assess whether it is possible to reduce carbon footprints by optimizing technology or switching to renewable energy.
Use phase (consumer use)	Durability and care: The lifespan and care of wool products are important considerations in LCA. The high durability of wool products means that they need less replacement, but frequent washing and drying can consume a lot of energy and water.

	Consumer behavior: LCA also assesses the environmental impact of consumers' use of wool products, such as laundry frequency, washing temperature, etc.
Waste phase (disposal and recycling)	Waste treatment: At the end of the life cycle, the way wool products are disposed of affects the environmental impact. LCA assesses whether the product is recycled, reused or ends up in landfill. Wool is highly biodegradable, so it has a lower impact when landfilled.
	Recycling and reuse: If wool products can be recycled or reused, such as the production of recycled wool, LCA will evaluate how this practice reduces the demand for new raw materials and reduces waste.

Table 3

Applications of LCA

Aspects	**Applications**
Environmental performance improvement	LCA helps the wool industry identify environmental hotspots at various stages, such as wool production, processing and transportation, and then proposes improvement suggestions, such as optimizing feeding management or using low-carbon energy.
Product design	Through LCA analysis, wool products can consider how to improve the environmental performance of products at the design stage, such as using sustainable wool, harmless dyes or reducing energy consumption.
Policy making and certification	LCA provides data support for policymakers to promote the wool industry to develop in a more environmentally friendly and sustainable direction. Many brands also obtain sustainable certification through LCA to meet market demand.

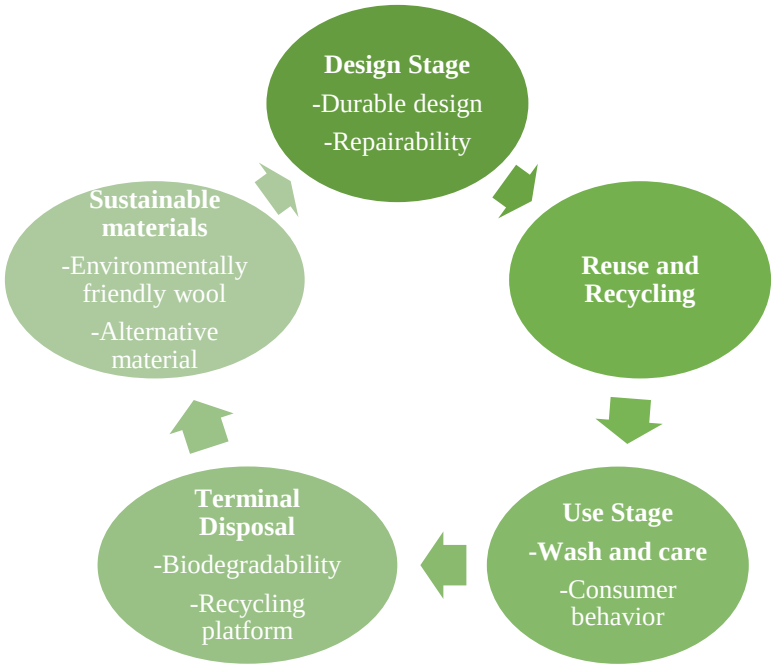
LCA in the wool industry involves the collection and analysis of data from multiple parties. Data from different regions and production methods may vary greatly, so data standardization and unification are one of the challenges of implementing LCA.Overall, Life Cycle Assessment (LCA) provides the wool industry with a scientific framework to help drive the industry towards a more sustainable direction by comprehensively analyzing the environmental impact of a product at every stage, from raw materials to waste.

2.3 Circular economy in wool design

The circular economy emphasises close-the-loop systems (Figure 1) where materials are reused and regenerated. Emphasis is placed on every link from design, production to final disposal. By extending the product life cycle, promoting recycling and reuse, and optimizing resource use, wool design can promote sustainable use of resources while reducing environmental impact. This model not only contributes to the sustainable development of enterprises, but also provides consumers with more environmentally friendly, economical and high-quality wool products.

Figure 1

Close-the-loop System in Wool



3 METHODOLOGY

3.1 Conceptual framework in table 4

Table 4

Conceptual Framework

No.	Action	Explanation
1	Analysis	Summarize and analyze the environmental impact of the fashion industry, the eco-friendly properties of wool, and the current inventory status of wool yarn and wool products through a literature review to emphasize the need for a systematic **Sustainable Design Toolkit (SDT)** for designers.
2	Develop a Sustainable Design Toolkit (SDT)	The application of existing sustainable design theories in wool is summarized in order to develop a comprehensive sustainable design toolkit (SDT) for wool products. In teaching and learning, there should be an ongoing enhancement of the toolkit. Designers ought to be encouraged to continually refine their understanding and application of sustainable design principles.

3.2 Toolkit development approach

There are four steps process in the development of SDT:

1. Literature Review:

   After studying the life cycle of wool products in depth to identify sustainability challenges during design, production, use and disposal. The possibility of existing sustainable design specifications for wool was summarized;

2.Interviews: Interviews with designers, lecturers, students and manufacturers to verify the importance of SDT;

3. Toolkit Design and Development: The toolkit was designed and developed to combine strategies and methods, in order to guide students, designers and manufacturers to make sustainable decisions in the process of wool product development.

3.3 Hypothesis

Main Hypothesis: The Wool Industry Sustainable Design Toolkit is an effective way to promote environmentally friendly design practices in the wool industry and improve product life cycle management.

Sub-hypothesis 1: Optimized material selection

Emphasize the sustainability of wool products in material selection, such as using recycled wool or wool fibers with low environmental impact. The goal is to reduce the use of new resources, reduce dependence on virgin wool, and reduce the environmental burden of resource extraction.

Sub-hypothesis 2: The close-the-loop awareness in the industry

Focus on the wool industry's understanding and application of the LCA method, that is, how to evaluate the environmental impact of the product's entire life cycle from raw material acquisition to disposal. It is assumed that the toolkit can promote the application of LCA, enabling companies to more systematically reduce carbon footprint and pollution during the design and production process.

Sub-hypothesis 3: The capacity improvement of industry practitioners

The focus is on the toolkit's training and capacity improvement of industry practitioners such as designers, manufacturers, and brands. It is assumed that the

sustainable design toolkit can improve the industry's overall environmental awareness and encourage companies to adopt more sustainable design and production strategies.

3.4 Case studies

Patagonia Recycling Wool Project (Wool, 2025)

Patagonia is well known for its sustainability and environmental efforts, and its wool recycling program, as well as its overall sustainability strategy, demonstrates its commitment to environmental and social responsibility. Here are some of the specific efforts and measures Patagonia has taken in these areas.

a. Goals and Philosophy:

Patagonia's wool recycling program aims to reduce material waste and promote a circular economy. The brand seeks to extend the life of the original material by transforming old wool garments into new products.

b. Specific Measures:

- Recycling Program: Consumers can return old Patagonia wool garments to the brand. Patagonia collects these items and reprocesses them to extract usable wool materials.
- Reusing and Reprocessing: Recycled wool is cleaned, sorted, turned into new yarn and fabric, and then used to make new garments or products. This approach not only effectively reduces waste, but also reduces the need for new resources.
- “Worn Wear” Program: Patagonia's Worn Wear program focuses on repairing, reusing and selling old clothes, including recycled wool products, encouraging consumers to reduce new purchases.

c. Overall Sustainability Strategy

Focus on Ecological Footprint: Patagonia publicly discloses the ecological footprint of its supply chain and production process, allowing public oversight to increase transparency. They are taking steps to reduce the use of water, energy, and chemicals to reduce the impact of their production process on the environment.

d. Sustainability of Raw Materials:

- **Organic Wool**: Most of Patagonia's wool comes from certified organic farms, aiming to support sustainable agricultural practices and avoid harmful chemicals.

- **Recycled Materials**: The brand uses recycled materials such as recycled polyester and recycled wool to reduce the demand for new raw materials.

e. Social Responsibility (Social Responsibility, 2025)

- **Education and Advocacy:** Patagonia actively engages in environmental protection advocacy and uses its influence to raise consumer awareness of sustainability. They provide resources on repair techniques and how to reuse clothing to help consumers extend the life of their clothes.
- **Fair Trade:** Patagonia is committed to producing products that meet fair trade standards, ensuring that workers' rights are protected, wages are fair, and they work in a safe environment.
- **Community Engagement:** The brand participates in various community environmental projects, supports local and global environmental organizations through donations and cooperation, and promotes sustainable development.

4 RESULTS AND DISCUSSIONS

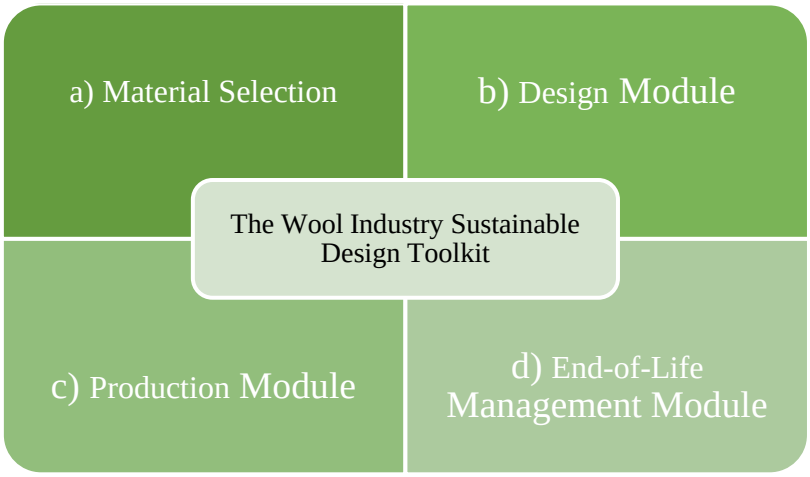
4.1 Key components of the toolkit

In my previous published paper, I have mentioned to design the sustainable design tools in sustainable education for fashion and textile design. In teaching and learning, the sustainable design tools should be an ongoing enhancement. (Li & Sindhuphak, 2024) The tools will continue to increase and enrich with sustainable design practices.

There are several key components in the toolkit, which are the basic modules to make up the toolkit. All tools can be divided into the following four modules.

Figure 2

Four Modules of The Wool Industry Sustainable Design Toolkit



a) Material Selection Module: Establish the sustainable materials databases

Table 5

Sustainable Materials Databases

Tool Name	Function Description	Suggested Visual Element and reference
1. Material Scoring System	Quantifies sustainability based on carbon footprint, water use, toxicity, renewability	Bar Chart, refer to the data from Higg Index
2. LCA Data Integration	Provides life cycle environmental impact data for each material	Circular Life Cycle Flow, refer to the data from OpenLCA
3. Sustainability Certifications Index	Lists certifications (e.g., RWS, GOTS) and links them to relevant materials	Certification Badge Icons
4. Traceability & Provenance Tracker	Tracks source farms, regions, and supply chain transparency	Interactive Map or Supply Flow Diagram, refer to the data from Blockchain-based traceability tool (e.g.,TextileGenesis)
5. Sustainable Alternatives Finder	Suggests lower-impact alternatives to conventional materials	Material Comparison Chart
6. Smart Filter & Search Engine	Allows filtering by use, certifications, performance, or impact score	UI Wireframe of Filters/Search Tool
7. Community Feedback Module	Enables designers and developers to review materials based on real-world performance	Star Ratings + Comment Box
8. Sample Request & Tracking Tool	Enables users to request material swatches and track feedback or testing outcomes	Sample Request Status Flowchart

b) Design Module: Establish the design guidelines and Frameworks

Table 6

Design Guidelines & Frameworks

Tool Name	Function Description	Suggested Visual Element	Reference / Inspiration Sources
1. Sustainable Design Principles Checklist	Checklist on recyclability, durability, biodegradability, modularity	Icon-based Matrix or Checklist	UN SDGs, Cradle to Cradle, Circular Design Guide (EMF)
2. Design for Longevity Framework	Guidelines for long-lasting wool products: timeless style, repairability, quality	Lifecycle Timeline or Pyramid	WRAP's Clothing Longevity Protocol, The Woolmark Company
3. Zero-Waste Pattern Library	A library of cutting patterns to reduce fabric waste	Blueprint or CAD Thumbnails	"Zero Waste Fashion Design" book, Fashion Revolution
4. Modular Design Toolkit	Design modular and interchangeable wool garments for repair or upcycling	Exploded Views or Assembly Sketch	OSCF Toolkit, IDEO Design Kit, Modular Clothing Project
5. Eco-Material Mapping Template	Link material choices to product zones (e.g. elbow with reinforced wool)	Material-Zone Mapping Chart	Higg MSI, Textile Exchange, Woolmark Fabric Insights
6. Digital Prototyping & Simulation Tools	Virtual fitting and material simulation reduce physical samples	3D Garment Rendering	CLO 3D, Browzwear, Adobe Substance, Woolmark Tools
7. Circular Design Flowchart	Visual guide of circular design paths: reuse, refurbish, disassemble, recycle	Loop Diagram with Circular Paths	Ellen MacArthur Foundation, Fashion for Good, Circle Economy
8. Emotional Durability Design Guide	Design strategies for emotional attachment to wool products	Storyboards, User Testimonials	Jonathan Chapman, Design Council UK, Woolmark Content
9. Sustainable Color & Trims Library	Curated eco-friendly dyes, buttons, threads for wool garment compatibility	Trim Swatch Board, Color Grid	GOTS Approved Lists, Bluesign®, Botanical Colors

c) Production Module: Establish the environmentally friendly production and manufacturing methods

Table 7

Environmentally Friendly Production

Tool Name	Function Description	Suggested Visual Element	Reference / Information Source
1. Clean Production Audit Checklist	Assesses energy, water, and chemical efficiency across production stages	Audit Sheet / Heatmap	ZDHC Clean Factory Approach, NRDC Clean by Design
2. Sustainable Dyeing Protocols	Guidelines for low-impact dyeing (e.g. enzyme-based, cold pad batch for wool)	Process Flow Diagram	Bluesign® System, GOTS Dyeing Manual, Woolmark Dye Guidelines
3. Water Recycling & Treatment Planning Tool	Helps plan wastewater reuse, filtration, and treatment systems	Flowchart + Filtration Diagram	ZDHC Wastewater Guidelines, ISO 14001, NIWA Guidelines

4. Renewable Energy Integration Planner	Identifies opportunities for solar, biomass, or heat recovery in wool processing	Solar/Energy Matrix	IEA Industrial Decarbonization, Textile Exchange Reports
5. Chemical Management System (CMS)	Tracks restricted substances, approved inputs, safe storage, and disposal	CMS Dashboard or Compliance Tracker	ZDHC MRSL, Bluesign®, REACH, GOTS Input Lists
6. Carbon Footprint Calculator for Manufacturing	Estimates GHG emissions from processes like spinning, scouring, dyeing, drying	Carbon Calculator / Emissions Bar Graph	Higg Facility Environmental Module (FEM), GHG Protocol
7. Worker Health & Safety Risk Mapper	Maps worker exposure to chemicals, heat, or dust during wool processing	Risk Zone Map / PPE Matrix	ILO Safety Standards, OHSAS 18001, Fair Wear Foundation
8. Wool Waste Sorting & Recycling Toolkit	Enables recovery of pre-consumer wool waste (e.g., yarn ends, offcuts) for reuse/recycling	Waste Sorting Chart or Color Codes	The Woolmark Company, Reverse Resources, Textile Recycling Best Practices
9. Process Optimization & Digital Monitoring Tools	Real-time tracking of water, energy, emissions, and yield efficiency	IoT Dashboards or Smart Sensors Map	ZDHC InCheck Tool, Higg FEM, LoRa/IoT in Smart Factories

d) End-of-Life Management Module: Follow the life cycle assessment

Table 8

End-of-Life LCA Tools

Tool Name	Function Description	Suggested Visual Element	Reference / Information Source
1. Life Cycle Assessment (LCA) Software	Quantifies environmental impact across the product's lifecycle: raw material → disposal	Sankey Diagram or Impact Chart	SimaPro, GaBi, OpenLCA, Ecoinvent, Higg MSI
2. Wool-Specific Environmental Impact Datasets	Provides LCA inventory data specific to sheep farming, scouring, spinning, etc.	Wool Flow Map	IWTO LCA Reports, Ecoinvent for Wool, Textile Exchange
3. End-of-Life Scenario Modeling Tool	Compares landfill vs composting vs recycling vs incineration outcomes	Scenario Matrix or Decision Tree	Ecoinvent, GaBi Scenario Tools, DEFRA EoL Models
4. Material Circularity Indicator (MCI)	Measures how circular a product is in its current form (e.g. mono-material wool content)	Spider Graph or Circularity Score	Ellen MacArthur Foundation – MCI Tool
5. Product Disassembly Mapping Template	Maps how products can be taken apart (for recycling, repair, reuse)	Exploded Product Diagram	OS Circular Fashion, Disassembly Case Studies
6. Post-Consumer Collection & Tracking Tool	Tracks product return, reuse, or resale metrics from customers	Tracking Flow or User Return Interface	Fashion for Good, CircularID, EPR Guidelines
7. Biodegradability Testing Protocol	Evaluates compostability or biodegradation performance of wool or wool-blends	Soil Breakdown Timeline	ISO 14851/52, ASTM D5988, The Woolmark Company

8. Take-Back Program Toolkit	Operational guide for brands to run product return programs	Closed-Loop Flowchart	Ellen MacArthur – Circular Business Models, Worn Again, I:CO
9. Consumer End-of-Life Education Material	Communication tools for educating users on disposal or return options	Instructional Cards / QR Codes	WRAP UK, Circular Textiles Alliance, TerraCycle Guides

4.2 Environmental benefits

The benefits to the environment can be explained as the following aspects:

- Resource Conservation: Precise material selection + zero-waste design reduces the exploitation and waste of natural resources (especially water and land) and improves the resource utilization rate of wool.
- Reduce carbon footprint: Optimizing processes (such as cold dyeing, renewable energy) and recycling strategies (such as take-back, remanufacturing) help reduce greenhouse gas emissions.
- Reduce water pollution: Reducing harmful chemicals (through tools such as ZDHC and GOTS) and adopting closed water systems can effectively control water pollution and toxic loads.
- Improve circularity: Through modular design, single-material structure, and detachable structure, wool products are easier to recycle or reuse, helping the industry enter a circular economy.
- Potential for soil and ecosystem restoration: Wool can be naturally degraded and can return to the soil under certain conditions to avoid microplastic residues, and has the ecological advantage of "natural destination".
- Enhance consumer environmental awareness: The educational tools in the Toolkit enhance consumers' sense of responsibility and participation in product use and promote the spread of environmentally friendly behaviors.

4.3 Challenges in implementation

- Cost and investment pressure: The initial investment in tools such as sustainable dyeing, renewable energy systems, and LCA modeling is large, which makes it difficult for small and medium-sized enterprises to bear.

- Insufficient technical capabilities: Factories or designers have insufficient experience in operating tools such as LCA software, CMS systems, and modular design.
- Difficulty in data acquisition and sharing: Especially in the upstream of the wool supply chain (pastures, washing), there is a lack of complete carbon, water, and energy consumption data, which affects accuracy.
- Difficulty in upstream and downstream collaboration: Modularization, recycling and other designs require cooperation from upstream and downstream of the supply chain, and suppliers are diverse and communication is complex.
- Market acceptance risk: Consumers' aesthetic and trust in recycled materials or environmentally friendly designs are unstable, which may affect product sales.
- Frequent updates of policies and regulations: Regulations on chemical emissions, carbon accounting, product labeling, etc. in various regions are rapidly iterating, and Toolkit needs to be continuously updated and adapted.

5 CONCLUSION

5.1 Summary

The Sustainable Design Toolkit provides a practical and systematic framework for designers and manufacturers aiming to reduce the environmental impact of wool products. By integrating existing sustainability-related standards in the wool industry, the toolkit provides designers with the most comprehensive sustainable design tool currently available. It is structured around the entire product life cycle - from material selection and design, to production, and end-of-life management - a true "whole life cycle tool". This study introduces the basic architecture and strategic development process of the toolkit, but the specific implementation and operation of each module will be the focus of subsequent research and publications.

5.2 Recommendations

- Promote cross-sector collaboration in the wool supply chain: Encourage greater collaboration between wool producers, manufacturers, designers, recyclers and

policymakers to align goals, share best practices and accelerate the scale-up of sustainable solutions.

- Strengthen consumer education and engagement: Develop a targeted communication strategy to increase consumer awareness of the environmental benefits of sustainable wool products and provide clear guidance on product care, disposal and return programs.
- Support innovation in recycling and biodegradation technologies: Prioritize investment in technical research, infrastructure development and pilot projects for wool recycling, closed-loop systems and biodegradation testing to achieve more circular and environmentally friendly end-of-life solutions.

5.3 Future research

Future research will focus on making the toolkit practical through tool development, field testing, and digital integration. In addition, localized, consumer-centric research, LCA data enrichment, and policy coordination are urgently needed to ensure its effective implementation and long-term impact. These future directions will help the toolkit evolve from a conceptual framework to a widely applicable industry standard.

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