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Tejiendo un futuro sostenible: avances de la industria textil en materiales y diseño ecológico

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Resumen: La industria textil, un sector clave de la economía global, enfrenta importantes desafíos para lograr la sostenibilidad a largo plazo debido a su impacto ambiental. Este capítulo explora los problemas ambientales de la industria, como el consumo excesivo de energía y las emisiones contaminantes, junto con su gran dependencia de recursos no sostenibles. En los últimos años se ha observado un cambio de paradigma hacia alternativas ecológicas, impulsado por la concienciación de los consumidores y la demanda de prácticas sostenibles. Además, se han aplicado fuertes medidas legislativas para reducir las emisiones de carbono y gestionar los residuos residuales, lo que indica un compromiso para lograr una economía más circular. Se ha explorado el uso de subproductos de la silvicultura, la agricultura y otras industrias para crear valiosas alternativas biomateriales al cuero y los materiales sintéticos. Debido a su abundancia y asequibilidad, los residuos que se pasan por alto, como el aserrín, la corteza de pino y la piel plateada del café, se muestran prometedores como materiales de base biológica. En este capítulo, evaluamos el uso de materiales sostenibles a través de metodologías de diseño ecológico, destacando su potencial para remodelar el sector textil y satisfacer las crecientes demandas de la sociedad de productos de moda respetuosos con el medio ambiente.

Palabras clave: Industria textil - ecodiseño - sostenibilidad - accesibibilidad

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Weaving a Sustainable Future: Textile Industry Advancements in Materials and Eco-Design

Introduction

The textile industry is one of the world's oldest and largest sectors, with its global value having a consistent annual increase (Roy et al., 2020). This dynamic industry, responsible for fabric and garment production, encompasses distinct products, ranging from automotive, construction, industrial, medical, protective, and sports textiles (Harsanto et al., 2023). Textiles are flexible materials manufactured through various processes, including weaving and knitting, using fibres that can be of natural or synthetic origin (Achaw & Danso-Boateng, 2021). Since the 1990s the production of synthetic fibres has surpassed the use of natural fibres (*e.g.,* cotton or wool), representing currently more than 64% of the used global fibres (Statista, 2023). The current global textile industry has been worth over $1 trillion since 2020 and has a projected CAGR (compounded annual growth rate) of 4.4% from 2021 to 2028. This continuous growth is evident in the worldwide production of textile fibres which amounted to around 24 million metric tons in 1975 and have reached an impressive volume of 113.8 million metric tons in 2022 (Wood, 2023).
The textile sector is one of the most important industries for the global economy with over 35 million employees worldwide through its long supply chains and having a direct impact on the survival of several other industries (Desore & Narula, 2018). However, is also recognised for the significant social and environmental problems it poses to long-term sustainability. Regarding the social aspect, in the textile sector, finished items are shipped from developing to developed countries in approximately 80% of the total flow (Niinimäki, 2015). Most textiles and clothing production takes place in southeast countries such as India, China, and Bangladesh where issues such as child labour, low-wage labour, and other unethical activities are prevalent (Guarnieri & Trojan, 2019). Moreover, the textile industry is also strongly associated with a negative environmental impact. Numerous environmental issues, notably the extensive energy consumption, and substantial pollutant

emissions have been associated with these industries. The textile business relies heavily on essential resources such as water, fuel, and chemicals, which are used in massive and unsustainable quantities. The water demand is particularly noteworthy, surpassing three trillion gallons of fresh water annually for global fabric manufacturing. The growing of cotton fibres, one of the most common natural fibres used, is estimated to consume around 8500 litres of fresh water to produce 1kg of these fibres (Desore & Narula, 2018).

Furthermore, this sector is responsible for nearly one-third of all chemicals released into the environment through emissions from textile treatment and dyeing processes. The disposal of vast quantities of toxic waste into the soil, air, and water over the years further exacerbates these environmental concerns (Niinimäki et al., 2020). Due to the energy-intensive manufacturing processes and the long supply chains, the apparel and footwear industries collectively contribute to 8–10% of global carbon emissions. Moreover, research underscores that up to 20% of industrial wastewater pollution is connected to textile dyeing and finishing activities. Additionally, with the rise of the industry, it is projected that the fashion industry will account for approximately 25% of the world's carbon budget by 2050 (Leal Filho et al., 2022). Despite the well-documented environmental repercussions, this industry keeps growing, driven in part by the rise of fast fashion. Fast fashion relies on inexpensive manufacturing, frequent consumption, and short-lived garment use. The demand for fast fashion has intensified the depletion of natural resources, amplifying ecological degradation, and contributing significantly to climate change (Niinimäki et al., 2020). Moreover, the textile waste in landfills has significantly grown in the last years considering that at the end of the product life cycle, only around 1% of textiles are recycled. For example, in the European Union (EU), each person uses nearly 26 kilos of textiles and discards about 11 kilos of them every year. The thrown fabrics can be exported and reused outside the EU market, but are mostly (87%) incinerated or landfilled, contributing to the current environmental crisis (European Parliament, 2023).

In recent times, the growing awareness by consumers regarding sustainability, climate crisis, and environmental degradation has led to a shift in the textile industry towards more sustainable practices. Furthermore, strong legislation has been passed in several developed countries to reduce the current emissions and improve the sustainability of the textile industry. In 2022, the European Commission presented a new strategy to make textiles more durable, repairable, reusable, and recyclable, tackling fast fashion and stimulating innovation within the sector. This strategy is a part of the EU plan to reach a circular economy by 2050, through the development of new technologies and the use of sustainable materials (European Parliament, 2023).

This noteworthy trend has generated increased interest in repurposing natural residues and innovating the creation of sustainable textiles. This shift reflects a broader commitment within the industry to embrace environmentally friendly alternatives, through a more responsible and ethical approach to textile production. The use of sustainable practices not only aligns with evolving consumer demands but also contributes to the industry's overall positive impact on the environment and society. In the following sub-chapter, we will explore possible sustainable materials that can be used as alternatives to leather and synthetic-based materials, contributing to enhancing the textile industrial sustainability, competitiveness, and resource independence.

Biobased Coated Materials - The rise of leather alternatives

The leather industry, recognized for its significant environmental impact, has drawn increasing attention and scrutiny from a more informed and conscientious society. The intricate process of leather manufacturing involves numerous steps, prominently featuring the tanning of raw animal skins using a diverse array of chemicals. Although leather is categorized as a bio-based material, relying on by-products from the food industry, particularly sourced from meat processing (Ozgunay et al., 2007), its production encompasses a complex series of procedures. The tanning process necessitates the use of various chemicals, including sodium chloride, ammonium chloride, sulphate, and chromium (Hashmi et al., 2017). Regrettably, this intricate procedure results in the generation of solid, liquid, and gaseous waste, releasing toxic chemicals with considerable environmental repercussions (Sivaram & Barik, 2019). This not only poses health risks for tannery workers but also exposes them to potential hazards associated with carcinogenic compounds (Hashmi et al., 2017). Moreover, it is imperative to underscore that specific leather varieties are sourced from exotic animals, such as alligators, snakes, and sharks, renowned for their unique patterns, naturally occurring marks, and distinctive structures (Demeroukas & Ritchie, 2015; Wainaina et al., 2022). Consequently, the leather industry has emerged as a focal point for substantial ethical concerns about animal rights and welfare, further exacerbating the challenges associated with environmental pollution. This heightened awareness, coupled with the industry's evident pollution, has spurred a growing interest in exploring alternative solutions to conventional leather.

Historically, synthetic materials, mainly originating from fossil-based sources, posed a significant challenge to leather due to their lower prices (Meyer et al., 2021). However, the environmental downsides linked to these alternatives, such as their non-biodegradability and detrimental manufacturing processes, have become increasingly evident. Synthetic alternatives to leather, predominantly comprised of polyvinyl chloride (PVC) or polyurethane (PU), contribute to pollution and resource depletion considering their reliance on fossil fuels (Jones et al., 2021; Meyer et al., 2021). Specifically, the production of PVC involves the utilization of toxic chemicals, yielding hazardous by-products like dioxins (Cao et al., 2013). PU, another common synthetic alternative to leather, requires toxic chemicals such as N,N-dimethylformamide for production (Zhao et al., 2018). Besides that, the textile industry extensively employs various plastics, including PA (nylon), PU (spandex), PE, PP (insulating polyolefins), and more recently, PET for nonwoven fabrics (Borriello et al., 2023; Nayar et al., 2016). The predominant use of fossil fuels in the production of these materials introduces greenhouse gas emissions associated with extraction and refining processes. Among the diverse associated problems, plastic pollution emerges as a critical issue, with the annual disposal of plastic posing severe environmental challenges (Nielsen et al., 2020). A staggering 60% of plastic waste, approximately 30 million tons per year (Browning et al., 2021), is inadequately managed and released into the environment, contributing to the global plastic pollution crisis. Efforts have been made to develop more biodegradable versions of PVC and PU, acknowledging the need for environmentally friendlier options.

The quest for leather alternatives that are less detrimental to the environment is crucial for mitigating the impact of the whole textile industry. In addressing these challenges, innovative solutions have emerged, trough the repurpose of by-products and waste from various sources such as agriculture, forestry, food, and industries to craft valuable biomaterials. These materials are commonly either utilized as biomass or discarded in landfills (Coelho et al., 2020; Gavahian et al., 2021).

For instance, the waste generated from the industrial processing of agricultural or animal products, categorized as agro-industrial waste, currently amounts to 2.01 billion tons, with projections estimating an increase to 3.40 billion tons by 2050 (Ahmad Khorairi et al., 2023). Additionally, global food loss and waste, approximately 1.6 billion tonnes annually according to the Food and Agriculture Organization (FAO), negatively impact food security, the economy, and the environment (FAO, 2018). The transformation of these waste and by-products into various value-added products has opened new avenues, contributing to environmental sustainability within the framework of a circular business model (Klai et al., 2021). Particularly, the application of these often-underestimated materials as bio-based coatings promotes innovation and flexibility within the textile industry. Thanks to their abundance and diverse compositions, these by-products inherently possess properties that can be exploited for textile coating applications (Silva et al., 2022). This versatility facilitates the creation of a wide array of textile products with enhanced performance attributes, distinctive aesthetics, and improved functionality (Zhang et al., 2022).

These sustainable alternatives are becoming increasingly accessible, with a diverse range of options already available, crafted from or incorporating various bio-based sources. Efforts have been made to diminish the non-renewable content in artificial leather alternatives by using agricultural waste-derived materials (Meyer et al., 2021). Instances of this trend include the integration of grape residues to craft a leather-like biomaterial (Vegea®, also known as Wine Leather) without water consumption, contributing to the growing array of sustainable leather alternatives in the market. Piñatex™, developed by Ananas Anam, utilizes pineapple leaf fibres to create a vegan alternative to traditional leather, prized for its strength, versatility, and eco-friendly properties (Meyer et al., 2021). Cork-based leather, campaigned by various brands, including Bleed, Pelcor, Stella McCartney, and Yves Saint Laurent, provides a sustainable option for fashion accessories, clothing, and more (Coelho et al., 2020). Wood-based leather, made from fast-growing trees and treated with non-toxic chemicals, is exemplified by Dolce & Gabbana and nat-2TM. Additionally, Gelatex, a non-woven fabric developed in Estonia, is made from gelatine derived from waste in the meat and leather industries (Coelho et al., 2020).

The use of recycled materials, particularly rubber, presents a different sustainable alternative, by repurposing an abundantly available yet unsustainable material. The recycled rubber addresses the longstanding environmental problems presented by the slow decomposition and hazardous by-products of these materials (Ravichandran & Natchimuthu, 2005). The exploration of bio-composite development, leveraging recycled waste resources, has gained substantial momentum in recent years as a viable substitute for leather. An exemplary initiative is embodied by RECYC Leather™, offering distinctive 100% recyclable leather alternatives. Comprising 60% leather fibres from manufacturing scraps, 30% synthetic/natural rubber, and a 10% water-based PU coating, these products, while not entirely biodegradable, make a valuable contribution to a circular economy through the recycling of waste materials (RECYC Leather, 2023). Another noteworthy instance of repurposing unsustainable materials is evident in the creation of materials from recycled plastic. Given the adverse effects of plastic pollution on our oceans, some companies like Adidas, are focusing on collecting plastic from ocean sources to manufacture new products. The recycling of disposed rubber and plastic provides a solution to extend the lifespan of these unsustainable materials and prevent increased environmental harm. Despite these strategies the main objective remains the overall reduction of their production (Kumartasli & Avinc, 2020).

Currently, there is a huge oversight in characterizing and considering certain by-products, thereby highlighting their potential as viable bio-based coatings. Recent research has made strides in evaluating previously overlooked residues, with sawdust, pine bark, and coffee silverskin emerging as promising bio-based materials for coating production. These residues, known for their abundance and cost-effectiveness, showcase unique properties (Eliche-Quesada et al., 2012; Nolasco et al., 2022; Silva et al., 2022). Sawdust, a by-product of the wood processing industry, demonstrates exceptional mechanical stability, a textured surface, heightened porosity, extensive surface area, substantial carbon content, and inherent biodegradability, making it versatile for various applications (Mallakpour et al., 2021). Its high absorbency further positions it as a promising material for efficient wastewater contaminant removal (Shukla et al., 2002). Pine bark, another abundant residue, holds significant potential for textile coating applications (Silva et al., 2022). Beyond providing a dark colour to the coatings, its inherent antioxidant, antimicrobial, and aromatic properties add value, enhancing the coating's appeal and functionality (Coelho et al., 2020; Maimoona et al., 2011). Coffee silverskin, the thin protective layer of the green coffee bean detached during the roasting phase, presents management challenges for roasting companies contributing to issues related to the disposal costs of substantial quantities of roasted coffee generated globally each year (Alves et al., 2017).

The process of creating a textile coating from these natural residues involves meticulous steps. These include the initial pre-treatment of the residue, where particle size reduction may be necessary to achieve a uniform and homogeneous coating, ensuring a pleasing tactile experience based on the intended application. Subsequently, the treated residue is blended with bio-polymers and crosslinkers. The resulting mixture is then carefully applied to selected textile substrates. To enhance the coating's characteristics, a calendaring process may be implemented, imparting specific textures, and further refining the final product. This comprehensive process ensures the seamless integration of natural residues into the textile coating, optimizing its properties and functionality. The application of residues like sawdust, pine bark, and coffee silverskin (Figure 1) as bio-based materials for coatings has yielded remarkable coatings with exceptional consistency and visual appeal. The sawdust imparts a golden-yellow hue, the pine bark contributes a purplish tint, and the coffee silverskin produces coatings in various shades of brown. These coatings exhibit a uniform texture and a pleasing softness, showcasing distinctive visual variations attributed to the natural colours of the utilized residues. As a result, each coating possesses a unique and individualized appearance. Moreover, employing diverse calendaring conditions facilitated the attainment of varied visual effects, expanding potential applications and emphasizing the versatility of using residues for coating production across different applications. Following the evaluation of their visual appeal, comprehensive preliminary tests were conducted on the coatings to assess their compliance with quality standards. These tests encompassed examinations of abrasion resistance, flexibility, and resilience to diverse environmental stresses, showcasing their robust endurance and potential practical applications. This innovative approach not only ensures the production of visually pleasing and versatile coatings but also contributes to the expansion of sustainable alternatives to traditional leather and synthetic materials. This emphasis on sustainable products underscores a commitment to diversify the market with environmentally friendly options, addressing the growing demand for ethical and eco-conscious alternatives within the textile industry.

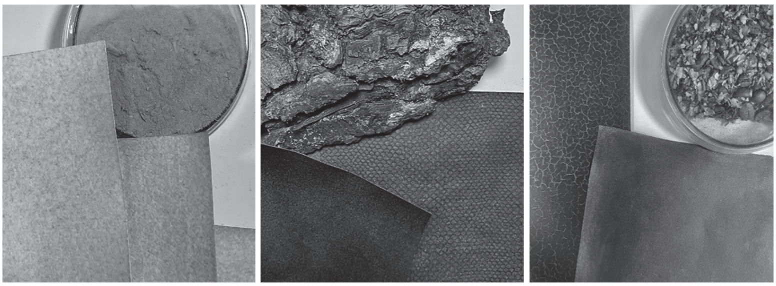

Figure 1. Bio-based coated materials with sawdust (left), pine bark (centre), and coffee silverskin (right).

Conclusions

The rise in environmentally conscious consumption has led society in general to focus on the sustainability of fashion products, showing a willingness to pay more for premium, eco-friendly offerings. In response, brands all over the world are adopting eco-design practices that consider all the environmental factors at every stage of product development by emphasizing sustainable and responsible measures (Yang et al., 2017). This approach involves the specific selection of materials, manufacturing processes, energy consumption, and end-of-life scenarios (Septiani et al., 2022). The prioritization of eco-friendly materials, by minimizing resource use and optimizing energy efficiency, lead to the development of innovative, functional, and sustainable products. Moreover, it promotes the adoption of circular economy principles, increasing the reusability and recyclability of by-products, critical aspects of sustainability. Through the integration of these principles, eco-design serves as a powerful tool for businesses and industries to align with global environmental goals and promote a more sustainable future (Septiani et al., 2022). The textile and fashion industry stands at a critical point, considering the huge challenges regarding waste and pollution, particularly evident in conventional leather production and the utilization of polyester textiles coated with fossil-based materials. The opportunity to use sustainable bio-based coatings derived from industry by-products is a promising alternative, offering a pathway towards more environmentally friendly and ethically conscious practices within the industry.

In the fashion industry, distinctive labels such as "ethical," "eco-friendly," "organic," "natural," and "fair trade" are strategically applied by brands to attract environmentally conscious consumers (Beard, 2008). However, the abuse of these terms and the lack of control over the product life cycle can create confusion among both companies and consumers. Moreover, if products are mistakenly labelled, a lack of trust towards this type of product can emerge in consumers, leading to problems in the transition towards sustainable textiles. In conclusion, strong legislation will be necessary to implement along the life cycle of products to verify the sustainability claims and to allow the organic growth of the eco-designed market. Although a careful balance between the economy and the environment is crucial for global economics, it is imperative to change the way that the textile industry works. Failure to do so may result in irreversible environmental damage, accentuating the urgency of this transformative shift.

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Abstract: The textile industry, a key sector of the global economy, faces significant challenges in achieving long-term sustainability due to its environmental impact. This chapter explores the industry's environmental issues, such as excessive energy consumption and pollutant emissions, alongside its heavy reliance on non-sustainable resources. In recent years, a paradigm shift towards eco-friendly alternatives has been observed, raised by consumer awareness and demand for sustainable practices. Moreover, strong legislative measures to reduce carbon emissions and manage residual waste have been enforced, signalling a commitment to achieve a more circular economy. The use of by-products from forestry, agriculture, and other industries has been explored to make valuable biomaterial alternatives to leather and synthetic materials. Due to their abundance and affordability, overlooked residues like sawdust, pine bark, and coffee silverskin show promise as bio-based materials. In this chapter, we assess the use of sustainable materials through eco-design methodologies, highlighting their potential to reshape the textile sector and meet society's rising demands for environmentally friendly fashion products.

Keywords: Textil industry - eco design - sustainability - affordability

Resumo: A indústria têxtil, um sector-chave da economia global, enfrenta desafios significativos para alcançar a sustentabilidade a longo prazo devido ao seu impacto ambiental. Este capítulo explora as questões ambientais da indústria, como o consumo excessivo de energia e as emissões de poluentes, juntamente com a sua forte dependência de recursos não sustentáveis. Nos últimos anos, tem-se observado uma mudança de paradigma em direção a alternativas ecológicas, suscitada pela consciencialização dos consumidores e pela procura de práticas sustentáveis. Além disso, foram aplicadas fortes medidas legislativas para reduzir as emissões de carbono e gerir os resíduos residuais, sinalizando um compromisso para alcançar uma economia mais circular. O uso de subprodutos da silvicultura, agricultura e outras indústrias tem sido explorado para criar alternativas valiosas de biomateriais ao couro e aos materiais sintéticos. Devido à sua abundância e acessibilidade, resíduos negligenciados como serragem, casca de pinheiro e casca de café mostram-se promissores como materiais de base biológica. Neste capítulo, avaliamos a utilização de materiais sustentáveis através de metodologias de design ecológico, destacando o seu potencial para remodelar o setor têxtil e satisfazer a crescente procura da sociedade por produtos de moda ecológicos.

Palavras-chave: Indústria têxtil - eco design - sustentabilidade - acessibilidade

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