Int. j. adv. multidisc. res. stud. 2024; 4(6):129-138

Received: 19-09-2024
Accepted: 29-10-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

The Role of Innovation in Making Fast Fashion Less Polluting

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Abstract
Fast fashion's breakneck pace leaves a trail of environmental destruction. This paper investigates how sustainable innovation can revolutionize the industry by fostering a Circular Fashion Economy. We analyze the potential of innovative materials, including bio-based fabrics and closed-loop recycling technologies, to lessen the environmental impact. Furthermore, sustainable processes that minimize water and energy consumption during production and dyeing are explored. The concept of a Circular Fashion Economy takes center stage, highlighting strategies like garment reuse, repair, and recycling to extend a product's lifespan. Through these advancements, the fashion industry can shed its fast fashion skin and embrace a more sustainable future.

Keywords: Sustainable Innovation, Fast Fashion, Materials, Sustainable Processes, Circular Fashion Economy

1. Introduction

In the ever-evolving landscape of the fashion industry, a paradigm shift is underway as the imperative for sustainability takes center stage. Within this dynamic context, the exploration of sustainable innovation in fast fashion emerges as a pivotal discourse, traversing realms of materials, packaging, processes, and the transformative concept of the Circular Fashion Economy. This paper delves into the intricate tapestry of initiatives and challenges that encapsulate the industry's pursuit of a more responsible and eco-conscious trajectory. As the clamor for sustainable practices reverberates, a nuanced understanding of the intricate interplay between innovation, consumer dynamics, and global supply chains becomes essential. This exploration navigates the complexities, both promising and elusive, as the fast fashion realm grapples with a transformative journey towards a more sustainable future.

2. Literature review

The Environmental Ramifications of Planned Obsolescence and Product Durability of Fast Fashion

Planned obsolescence, a strategic design practice, intentionally shortens the lifespan of products to stimulate frequent replacements. This pervasive business tactic within the realm of consumer goods carries extensive ecological and societal repercussions (Lieselot Bisschop, Yogi Hendlin & Jelle Jaspers, 2022) [6]. This approach not only affects our environment but also has profound implications for our society. Planned Obsolescence involves the creation of goods with deliberately short lifespans, compelling consumers to make repetitive purchases (Jeremy Bulow, 1986) [7]. This strategy plays on the idea of 'use it and lose it,' ultimately shaping our consumption patterns. Rooted in fashion and marketing principles (Julio L. Rivera and Amrine Lallmahomed, 2015) [43], this concept hinges on the premise that when people embrace newer product versions, the value of the older ones rapidly diminishes. In essence, it's a constant race for the latest and greatest. This frequent replacement culture leads to the rapid disposal of retired products, contributing significantly to waste generation (Julio L. Rivera and Amrine Lallmahomed, 2015) [43]. Our throwaway mentality drives landfills to their brim.

The creation of both functional and psychological obsolescence serves as a means to generate demand for new products. However, this demand often emerges artificially, manufactured by sellers rather than arising from genuine customer needs (Julio L. Rivera and Amrine Lallmahomed, 2015) [43]. It's a tantalizing dance between consumer desire and corporate manipulation.

Coined by The New York Times in the 1990s, “fast fashion” characterizes a business strategy focused on streamlining the buying process and expediting the introduction of new fashion items into stores, all in response to consumer demand peaks (Barnes and Lea-Greenwood, 2006). In essence, the fast fashion relies on Planned Obsolescence as strategic design choice.

Many apparel companies have wholeheartedly embraced the fast fashion model, effectively reducing the life cycle of fashion items and consistently releasing new clothing, thereby encouraging frequent consumer purchases (Caro and Martínez-de- Albéniz, 2015) [8], (Choi, 2014) [10], (Niinimäki *et al*., 2020) [40].

Fast fashion exhibits a brief life cycle, often lasting no longer than a month (Joung, 2014) [29]. This relentless pace demands constant adaptation and turnover. Fast fashion is a business model characterized by its rapid response, frequent changes in product assortments, and the offer of trendy designs at budget-friendly prices (Caro & Martínez-de-Albéniz, 2015) [8]. It’s a delicate balance between affordability and ever-evolving style.

While seemingly catering to consumers’ craving for the latest fashion trends at reasonable costs, this accelerated culture of replacement within the fashion industry exacts a toll on the environment and sustainability patterns. It encourages both frequent purchases and disposals, straining our ecological and ethical boundaries (Vitorino, Andreia Filipa Martins, 2016) [54]. It’s a price we pay for staying in vogue.

The Unfair Environmental Footprint of Fast Fashion

The textile and fashion industry operates through an intricate supply chain that encompasses various stages, commencing with agriculture and petrochemical production, necessary for fiber generation, and extending to manufacturing, logistics, and retail (Kirsi Niinimäki, Greg Peters, Helena Dahlbo, Patsy Perry, Timo Rissanen & Alison Gwilt, 2020) [40]. This extensive network presents a multi-faceted challenge in terms of environmental sustainability.

In a startling revelation, the fashion industry has now claimed the unenviable rank of being the second most polluting industry globally, trailing only behind the formidable oil extraction and production sector (Diabat *et al*., 2014) [12]. This dubious distinction underscores the urgent need for reevaluating its environmental impact.

Scholars have been vocal about the ecological toll exacted by the fashion industry, emphasizing issues like excessive water consumption and water contamination (Abbas *et al*., 2020). These environmental concerns loom large, demanding immediate attention and remediation.

At every stage of production, from the initial processing to final product assembly, the fashion industry leaves a significant environmental footprint due to water utilization, material consumption, chemical usage, and energy expenditure (Kirsi Niinimäki, Greg Peters, Helena Dahlbo, Patsy Perry, Timo Rissanen & Alison Gwilt, 2020) [40]. Each of these steps adds to the industry’s environmental burden.

Scholars have shed light on various environmental impacts tied to the industry, including excessive water use, water pollution (Abbas *et al*., 2020), greenhouse gas emissions from fossil fuel processing, and the use of hazardous chemicals (Khurana & Ricchetti, 2016) [32]. Shockingly, the industry is accountable for a staggering 10% of annual global carbon emissions, equivalent to emissions from international flights and maritime shipping. This figure is projected to surge by over 50% by 2030 (World Bank, 2019).

The inception of the global textile supply chain begins with textile production, involving the creation of both natural and synthetic fibers. Notably, nearly 90% of clothing sold in the United States is manufactured from cotton or polyester, both of which have well-documented health implications stemming from their production processes (Khan, S. and A. Malik, 2014) [30].

Polyester, a synthetic textile, originates from oil, while cotton cultivation demands substantial water and pesticide usage (Khan, S. and A. Malik, 2014) [30]. Shockingly, in 2015, the fashion industry consumed a staggering 79 billion cubic meters of water. To put this into perspective, crafting a single T-shirt necessitates a staggering 2700 liters of water (European Parliament, 2021). The dyeing of textiles further compounds the issue, as untreated wastewater filled with dyes is frequently discharged into local water systems, releasing heavy metals and other toxic substances that harm both wildlife and nearby communities (Khan, S. and A. Malik, 2014) [30]. This adds to the global water pollution crisis, with textile dyeing and finishing alone contributing to 20% of the problem, while washing synthetic fiber garments releases 0.5 million tonnes of microplastics into the oceans annually (European Parliament, 2021).

The industry’s environmental implications extend to air pollution as well, with it being responsible for 10% of global greenhouse gas emissions (European Parliament, 2021). This exacerbates concerns about air quality (Jia *et al*., 2020; Niinimäki & Hassi, 2011 [39]), posing further challenges in mitigating the industry’s overall impact.

Garment assembly, the subsequent stage in the global textile supply chain, relies on a workforce of 40 million individuals worldwide (Siegle L. 2011) [51]. However, this labor-intensive process carries numerous occupational hazards, ranging from respiratory issues caused by inadequate ventilation, such as cotton dust and synthetic air particulates, to musculoskeletal problems resulting from repetitive tasks (Sant’Ana MA, Kovalechen F., 2012) [47].

Beyond the environmental and occupational concerns, scholars have emphasized the industry’s adverse societal impacts, which include subpar working conditions (Haug & Busch, 2015) [23], health and safety hazards (Cesar da Silva *et al*., 2021) [9], and egregious human rights abuses such as child labor and modern slavery (Peake & Kenner, 2020; Thorisdottir & Johannsdottir, 2020). These pressing issues underscore the need for a holistic and responsible transformation of the fashion industry.

Innovation in the Fast Fashion Industry

Ensuring equity in the global supply chain’s environmental aspects poses an ongoing challenge. The achievement of worldwide environmental justice hinges, in part, on the breakthroughs emerging within the realm of textile innovation.

Sustainability within the domain of fibers extends to the adoption of practices and policies that mitigate environmental contamination and reduce the exploitation of natural resources and human labor to meet the demands of modern living. While natural cellulosic and protein-based fibers are generally lauded for their eco-friendliness and their positive effects on human well-being, there are instances where synthetic fibers are deemed to offer a more sustainable alternative. For instance, fabrics like Lyocell, derived from bamboo cellulose, undergo a closed-loop production process where an impressive 99% of the chemicals used in fabric fiber creation are recycled. The utilization of such sustainable fibers plays a pivotal role in curbing the ecological footprint left by textile production.

Problem Statement: "Balancing the Unfair Environmental Footprint of Fast Fashion with Innovations in Fibers and Textile"

The global fashion industry, particularly fast fashion, has emerged as a significant contributor to environmental degradation, marked by excessive resource consumption, pollution, and wasteful practices. Simultaneously, the textile industry is witnessing advancements in fibers and textiles that hold the promise of more sustainable and environmentally friendly materials. The challenge at hand is finding a harmonious equilibrium between addressing the environmental injustices inherent in the fast fashion sector and harnessing these innovations to transition towards a greener, more equitable fashion landscape. Research is required to explore how these innovations can be effectively integrated into the fast fashion supply chain and whether they can genuinely mitigate the industry's detrimental impact on the environment and societal well-being.

3. Methodology

The initiation of this research project involved a systematic exploration of fundamental concepts, conducted through a careful review of scholarly articles and research papers from prominent platforms such as Google Scholar and Cairn. These platforms, renowned for their wealth of academic knowledge, helped to unravel the concepts identified, offering diverse perspectives and detailed insights.

The initial stage focused on a thorough selection of relevant literature. Google Scholar, a leading repository of peer-reviewed articles, theses and research papers, was used as the cornerstone of the information retrieval process. A refined search strategy was employed to sift through the abundance of material available, ensuring the selection of sources marked by relevance and scientific rigor. At the same time, the exploration was extended to Cairn, which stands out for its vast collection of academic journals. This dual approach facilitated a nuanced and multifaceted understanding of the targeted concepts.

As the research progressed, the next imperative was the meticulous organization of the data amassed. The voluminous ideas harvested from a variety of sources needed to be systematically arranged to reveal the interwoven threads. Each concept identified played the role of a fundamental element, strategically positioned to build a coherent narrative. The organizational architecture aimed not only at clarity, but also at fostering a seamless transition between concepts, allowing a harmonious flow of ideas. Using tools such as mind maps and thematic analysis, the data was meticulously categorized, facilitating a nuanced exploration of the relationships and patterns intrinsic to the research findings. Once the data structure had been established, the culminating phase consisted of synthesizing the results to draw meaningful conclusions. The combination of information from Google Scholar and Cairn converged into a coherent narrative that answered the central research questions. Patterns, trends and anomalies in the data were subjected to rigorous scrutiny, yielding valuable insights into the subtleties of the chosen concepts. The resulting conclusions extend beyond simple summary, embodying thoughtful interpretations that call for deeper contemplation and discourse.

4. Results

Within this segment, we delve into the outcomes to tackle the posed research inquiries. The initial query probes the existing landscape of sustainability innovation within the textile industry, encompassing both advancements in textile and fibers, packaging, as well as innovations in the procedural aspects. The subsequent question delves into identifying a preferred model conducive to fostering a business environment that leans towards greater environmental sustainability.

4.1 Types of Innovations in Fast Fashion

4.1.1 innovation in sustainable materials

The material theme refers to efforts to reduce, replace, or use more sustainable materials as part of sustainability innovation. (Hens, L *et al*., 2018) [24].

This form of sustainability innovation is critical because the majority of materials used in the textile industry are unsustainable, such as fibers derived from fossil fuel sources (Adu, C. *et al*, 2022).

To provide more sustainable fibers, for example, an innovative effort is being made to develop regenerative cellulose filaments from a paper mill sludge-based material dissolved in an ionic liquid. When compared to less sustainable materials, the result is fibers that are both regenerative and competitive (Adu, C. *et al*, 2022).

A diverse array of natural resources, such as bananas, coffee, pineapple, lotus, stinging nettles, and hemp, presents promising alternatives to traditional fabric sources. This diverse spectrum of organic materials holds the promise of not only meeting but exceeding the demands of modern textile production, providing a holistic and ecologically sound approach to meet the ever-growing needs of the fashion and textile industries.

a. Hemp Fibers

Hemp stands out as an exceptional natural fiber, possessing a versatility that extends beyond its counterparts. Derived from the hemp plant, hemp fibers exhibit not only antibacterial properties but also durability and resilience, functioning akin to a natural air-conditioning system. The plant's rapid growth rate, coupled with its minimal water requirements and independence from herbicides, pesticides, synthetic fertilizers, and GMO seeds, prompts contemplation regarding why this ecologically beneficial plant has not yet been universally embraced as the standard in textile processing. This multifaceted analysis seeks to unravel the untapped potential of hemp fibers in promoting sustainable practices within the textile industry.

b. Stinging Nettle Fibers

The common stinging nettle, scientifically known as Urtica dioica, has proven to be a highly versatile and readily available plant for sustainable textile production. The meticulous process of harvesting stinging nettles during the summer, coupled with subsequent stages such as thorough drying to eliminate stings, breaking to segregate woody components, and hackling to extract fibers, highlights the intricacies involved in transforming this plant into a viable textile resource. Moreover, the spinning and drying procedures enhance the tear resistance of stinging nettle fibers, positioning them as a viable and promising material for sustainable textile production practices.

c. Coffee Ground Fibers

In a seemingly mundane act of discarding coffee grounds post-brewing, lies an untapped resource that has the potential to revolutionize sustainable textile production. Innovations by Taiwanese textile company Singtex involve the integration of post-patented processed coffee grounds with polymer, resulting in master batches that are subsequently spun into versatile yarn. This coffee yarn, characterized by its multi-functionality, finds applications ranging from outdoor and sports performance wear to commonplace household items, demonstrating the transformative potential of reimagining waste materials for sustainable textile production.

d. Pineapple Fabric Piñatex

Ananas Anam's groundbreaking creation, Piñatex, represents a vegan alternative to leather, harnessing the potential of pineapple leaves. The meticulous process of decortication, involving the extraction of fibers from pineapple leaves, forms the foundation for Piñatex. This natural and non-woven textile closely mimics the texture of leather, presenting a viable eco-friendly option. Furthermore, the by-products generated during the manufacturing process, such as biomass, are ingeniously repurposed into organic fertilizer or bio-gas, creating a sustainable closed-loop system in the production of Piñatex.

e. Banana Fibers

Derived from the robust stem of the banana tree, banana fibers emerge as one of the world's strongest natural fibers. The composition of these fibers, characterized by thick-walled cell tissue bonded together by natural gums and primarily composed of cellulose, hemicelluloses, and lignin, distinguishes banana fibers from their counterparts such as bamboo. The superior spin ability, fineness, and tensile strength of banana fibers position them as an ideal candidate for various textile applications, with the potential to produce diverse fabrics based on the extraction point on the banana stem. This section thus unfolds the intricate details and remarkable qualities inherent in banana fibers.

f. Lotus Fibers

While the use of lotus fabrics and textiles might sound exotic to Western sensibilities, in countries like Thailand and Myanmar, lotus fibers have been integral to traditional garment production for centuries. The manufacturing process, though complex and lengthy, yields a luxurious fabric that exudes a unique blend of silk and raw linen characteristics. This section explores the historical significance of lotus fibers in textile production, emphasizing their stain-resistant, lightweight, soft, silky, and extremely breathable attributes. Moreover, the challenges posed by the intricate manufacturing process involving lotus stems are examined in detail, providing a comprehensive understanding of the potential and hurdles associated with integrating lotus fibers into contemporary sustainable textile practices.

4.1.2 innovation in packaging

The imperative for the development of novel, sustainable packaging technologies is underscored by environmental considerations and the promotion of a circular economy (Guillard V, Gaucel S, Fornaciari C, Angellier-Coussy H, Buche P and Gontard N, 2018) [19]. Focusing on alternatives in packaging that are environmentally friendly plays a pivotal role in minimizing the ecological footprint. Consequently, sustainability in packaging assumes paramount significance within the fast fashion industry, given its substantial contribution to global waste and environmental impact.

Several noteworthy developments and trends characterize sustainable packaging within the fast fashion sector:

4.1.3 Innovations in the production processes

4.1.3.1 Ecodesign

Ecodesign is a systematic attempt to integrate environmental considerations into the development of products and processes (Salo, H.H.; Suikkanen, J.; Nissinen, 2020) [45]. Moving away from conventional product design, DfE takes a holistic approach, examining the whole supply chain, taking into account not only recycling aspects, but also giving the design an objective of both recycling and longevity (Gu, C.; Xu, C.; Zhou, Q.; Shen, C.; Ma, C.; Liu, S.; Yin, S.; Li, F., 2021) [18]. DfE research covers a variety of fields, encompassing the intersections between DfE and other research disciplines such as design, management, psychology and sociology (Schäfer M, Löwer M., 2021) [48]. A study of three major global fashion and apparel cases found that environmental competencies in industrial design include the five Rs - reimagining, redesign, reuse, reduce and recycle - which effectively improve internal efficiency by significantly reducing energy consumption and waste (Wong, D.T.W.; Ngai, E.W.T., 2021) [55]. Tools commonly used in ecodesign within the textile industry include ecolabels, carbon footprints, life cycle assessment, design for sustainability and water footprints (Salo, H.H.; Suikkanen, J.; Nissinen, 2020) [45].

Nevertheless, the widespread adoption and implementation of effective DfE strategies faces various barriers and success factors that require special attention to promote their integration into the industry (Schäfer M, Löwer M., 2021) [48]. The main challenges for DfE research are to identify and address emerging issues, such as the DfE paradox. This paradox refers to the challenges associated with integrating sustainability principles into research and development projects (Natalia Chebaeva, Miriam Lettner, Julia Wenger, Josef-Peter Schöggl, Franziska Hesser, Daniel Holzer, Tobias Stern, 2021) [37].

4.1.3.2 Life Cycle Assessment (LCA)

Life cycle analysis (LCA) stands as a methodology devised to pinpoint critical junctures in industrial processes and identify opportunities for enhancing various technological solutions, thereby fostering environmental innovation and efficiency (Köhler, A.R.; Som, C., 2014) [34]. Acknowledged as an indispensable tool, LCA facilitates the assessment of ecological burdens and impacts across consecutive and interlinked stages within a product system, spanning from raw material extraction to disposal. This methodology has garnered recognition through publications such as The International Journal of Life Cycle Assessment (The International Journal of Life Cycle Assessment) (Köhler, A.R.; Som, C., 2014) [34].

In the textile industry, LCA holds significance due to the potential environmental and social impacts at each stage of the industrial process. These stages encompass manufacturing, which may involve the use of toxic chemicals or substantial energy consumption, to the end-of-life stage, where certain products emit hazardous chemicals upon disposal in landfills [Klewitz, J.; Hansen, E.G., 2014) [33] (Harsanto, B.; Permana, C.T., 2021) [22]. The assessment methodology employed in LCA relies on standardized procedures and guidelines, as exemplified by the ISO 14040 series, providing a framework for conducting LCA studies (Khasreen MM, Banfill PFG, Menzies GF., 2009) [31].

Furthermore, LCA studies have showcased the collaborative potential of LCA and risk assessment within a framework inclusive of multiple impact categories, thereby contributing to the decision-making process (Jeroen B. Guinée, Heijungs R., Huppes G., Zamagni A., Masoni P., Buonamici R., Ekvall T., and Rydberg T., 2011) [28].

In summary, LCA represents a valuable tool for evaluating the environmental impact of products and processes, facilitating the identification of opportunities for improvement and optimization.

4.1.3.3 Cleaner Production

Cleaner Production is a research field that focuses on reducing the environmental impact of industrial processes and products by optimizing resource use, minimizing waste, and improving efficiency. (The Journal of Cleaner Production) [52].

Cleaner Production research covers a wide range of topics, including sustainable manufacturing, green chemistry, and circular economy (The Journal of Cleaner Production) [52].

Researchers have also explored the application of Cleaner Production in various industries, such as food production and construction (The Journal of Cleaner Production) [52].

Cleaner Production is closely related to other research fields, such as Life Cycle Assessment (LCA), which is often used to evaluate the environmental impact of Cleaner Production strategies (Journal of Cleaner Production, Published by Elsevier BV).

Overall, Cleaner Production is a valuable research field that aims to promote sustainable industrial practices and reduce the environmental impact of human activities.

4.1.3.4 Ecoefficiency

Ecoefficiency is a research field that aims to optimize the use of resources and minimize waste while improving economic performance and reducing environmental impact. Researchers have proposed different approaches to measure ecoefficiency, such as the ratio of economic performance to environmental influence, the ratio of environmental performance to economic performance, and the general goal of creating value while decreasing environmental impact, in simple terms, the idea of “creating more value with less environmental impact” (Zhao, Y., & Li, R., 2023) [56].

Ecoefficiency holds paramount importance in the textile industry due to its extensive consumption of resources such as water, electricity, and various chemicals throughout an extended production process (Köhler, A.R.; Som, C., 2014) [34]. An examination of the environmental impact of water-use systems in the textile industry, based in Biella, Italy, revealed that resource efficiency can be enhanced through the implementation of intelligent pumping systems, automated dye and chemical dispensing, low liquor ratio jet dyeing machines, as well as pollution prevention and control measures employing natural dyes, advanced oxidation processes with Fenton’s reagent, and membrane bioreactors (Armstrong, C.M.; Niinimäki, K.; Kujala, S.; Karell, E.; Lang, C., 2015) [4]. Through the introduction of an innovative dyeing protocol, it was reported that production costs were reduced by approximately 50%, accompanied by a corresponding decrease in CO_2 emissions of around 55% compared to conventional protocols (Parisi, M.L.; Fatarella, E.; Spinelli, D.; Pogni, R.; Basosi, R., 2015) [42].

The genesis of ecoefficiency predominantly emanates from technological advancements, symbolizing the substitution of machinery or equipment with cutting-edge technology to diminish environmental impact (Schellenberger, S.; Hill, P.J.; Levenstam, O.; Gillgard, P.; Cousins, I.T.; Taylor, M.; Blackburn, R.S., 2019) [49]. Examples of resource-efficient technologies encompass smart pumping systems, jet dyeing, and jet weaving looms. In the case of jet weaving looms, the efficiency gains are notable, providing nearly twice the performance of the old technology with almost identical resource consumption (880 RPM compared to 490 RPM) (Schellenberger, S.; Hill, P.J.; Levenstam, O.; Gillgard, P.; Cousins, I.T.; Taylor, M.; Blackburn, R.S., 2019) [49].

Pollution-prevention technologies, such as the advanced oxidation process and membrane bioreactors, also exemplify ecoefficient measures in the textile industry (Armstrong, C.M.; Niinimäki, K.; Kujala, S.; Karell, E.; Lang, C., 2015) [4]. The overall value added through the adoption of replacement technology, in comparison to the total investment made, yielded positive returns, delivering approximately 1.5 times the baseline performance of the old technology (Angelis-Dimakis, A.; Alexandratou, A.; Balzarini, A., 2016) [3].

The evaluation of ecoefficiency often involves non-parametric frontier efficiency analysis methods, such as Data Envelopment Analysis (DEA) (Zhao, Y., & Li, R., 2023) [56].

4.1.3.5 Waste Handling

Waste handling emerges as a facet of sustainability innovation with a dedicated focus on initiatives aimed at diminishing, reusing, or recycling waste (Hens, L *et al*., 2018) [24]. In the textile industry, waste poses a significant global concern, prompting strategic measures recommended by the literature. These measures involve meticulous attention to raw materials, efficient waste management practices, and an in-depth understanding of consumer behavior. A study conducted on 48 textile companies in the Yangtze River Delta area of China identified chemical fiber manufacturing’s raw materials, particularly perfluorinated compounds (PFCs), as the primary source of pollution (Gu, C.; Xu, C.; Zhou, Q.; Shen, C.; Ma, C.; Liu, S.; Yin, S.; Li, F., 2021) [18].

To address this challenge, pollution reduction strategies involve collaborating with raw material providers, implementing specific agreement schemes to regenerate waste generated from the production process (Siderius, T.; Poldner, K., 2021) [50]. Simultaneously, endeavors to minimize waste include innovating raw materials to align with existing regulations while providing added value for the company (Sandvik, I.M.; Stubbs, W., 2015). In Vietnam, for instance, stringent regulations restrict the use of endocrine-disrupting surfactants, compelling textile companies to adhere to these provisions (Achabou, M.A.; Dekhili, S.; Codini, A.P., 2020) [1].

In the realm of waste management, innovative approaches encompass the utilization of magnetic titania nanophotocatalysts for the photocatalytic creation of fuel gases, essentially transforming waste into energy (Harifi, T.; Montazer, M.; Dillert, R.; Bahnemann, D.W., 2018) [21]. Another noteworthy example is the development of an integrated system involving plasma pretreatment and biosynthesis (Köhler, A.R.; Som, C., 2014) [34].

Furthermore, understanding and shaping consumer behavior, facilitated through various communication channels, including digital platforms, assume equal importance. As consumer interest grows, activities like garment recycling are emerging as efforts to establish circular products, gradually becoming the "new normal" (Bhamra, T.; Hernandez, R.J.; Rapitsenyane, Y.; Trimingham, R., 2018) [5].

4.1.3.6. Enzymatic textile process

Enzymatic textile processing is a sustainable and environmentally friendly alternative to conventional textile processing methods. Enzymes can be used in various stages of textile production, including desizing, scouring, bleaching, and finishing. Enzymatic treatments have been shown to improve the properties of cotton and polyester textiles, and can be used for textile recycling. Enzymatic textile processing can conserve energy and reduce the use of harsh chemicals, making it a promising approach for sustainable textile (Mojsov, Kiro, 2012 et J. Shen, E. Smith, 2015) [35, 26].

The enzymatic textile process is integral at various stages of the intricate textile production, spanning from raw fabric production to finishing, encompassing operations in both textile mills and laundries (Gotmare, V.D.; Kole, S.S.; Athawale, R.B., 2018) [17]. Instances of this enzymatic intervention include fiber modification during raw fabric production, desizing, and scouring in the preparation stage, bleach cleaning and dyeing in the dyeing stage, and softening in the finishing stage (Gotmare, V.D.; Kole, S.S.; Athawale, R.B., 2018) [17].

A noteworthy example involves utilizing crude enzymes derived from Aspergillus niger to convert tea polyphenols into pigments via bioconversion or enzymatic synthesis of biodyes on a semi-industrial scale using a bioreactor and reverse osmosis apparatus (Gopalakrishnan, S.; Matthews, D., 2018) [16]. The use of enzymes has demonstrated effectiveness in reducing energy consumption and waste in the textile process (Gopalakrishnan, S.; Matthews, D., 2018) [16].

However, the implementation of enzymatic-based textile processes encounters diverse challenges, stemming from socioeconomic and regulatory factors (Gotmare, V.D.; Kole, S.S.; Athawale, R.B., 2018) [17].

4.2 A sustainable model: Circular Fashion Economy

The Circular Fashion Economy is a concept that aims to reduce waste and promote sustainability in the fashion industry by keeping clothing and accessories in circulation for as long as possible. This approach involves various strategies, barriers, and enablers that facilitate the transition towards a more sustainable and circular fashion industry.

Within the fashion industry, design plays a pivotal role in establishing a closed-loop system, aiming to prolong the lifespan of garments through enhanced durability and universality, while also facilitating the recovery and recycling of raw materials through multiple cycles (Niinimäki Citation 2017; Muthu Citation 2018) [38, 36]. These endeavors hinge on decisions made by designers regarding material selection, clothing construction, and finishing processes (Gwilt Citation 2014; Muthu Citation 2018) [20, 36].

Moreover, sound design practices can contribute to the enhancement of material selection, standardization of product design, modularization of components, establishment of more streamlined material flows, and the creation of designs conducive to easier disassembly. These considerations not only facilitate commercial and technological viability for remanufacturing or recycling but also contribute to the overall success of closed-loop systems.

Some key aspects of the Circular Fashion Economy include:

Strategies: Circular fashion strategies focus on extending product lifespans, reducing waste, and promoting recycling and reuse. These strategies can involve design innovations, material choices, and business models that emphasize sustainability and social responsibility (Jansson D. & sjöbohm V., 2022) [27].

Barriers: Implementing circular fashion strategies can be hindered by various barriers, such as lack of consumer awareness, regulatory challenges, and resistance from established businesses. These barriers can limit the adoption of circular fashion practices and hinder the transition towards a more sustainable industry (de Aguiar Hugo A, de Nadae J, da Silva Lima R., 2021) [11].

Enablers: Enablers are factors that facilitate the adoption of circular fashion strategies, such as technological innovations, consumer demand for sustainable products, and supportive government policies. These enablers can help overcome the barriers and drive the growth of circular fashion practices in the industry (de Aguiar Hugo A, de Nadae J, da Silva Lima R., 2021) [11].

Practices: Circular fashion practices can vary depending on the specific context and challenges faced by the fashion industry. Examples of these practices include designing for fast and slow circular fashion systems, exploring strategies for multiple and extended product cycles, and investigating circular economy practices in different countries and regions (Erminia D'Itria & Reet Aus, 2023) [15].

Eionet proposes several measures to facilitate the shift from linear to circular textile industries, with a central emphasis on design choices. The report underscores the significance of incorporating sustainability into design education curricula, highlighting it as a potent catalyst for transforming design culture (EEA/Eionet Citation 2019). Additional actions include the implementation of extended producer responsibility schemes and the transition from linear to circular business models.

Many of these recommendations are poised to transition into legislative measures by 2025, intensifying the urgency for the Fashion Industry to accelerate its move towards Circular Economy (CE). Consequently, this increased urgency will extend the pressure to expedite the transition to CE, impacting the roles of designers in this transformative process.

Circular Fashion Economy faces substantial challenges:

In spite of these alluring aspects, the Circular Fashion Economy faces substantial challenges. Implementation necessitates seamless collaboration across intricate global supply chains. Coordinating efforts among manufacturers, suppliers, retailers, and consumers poses a significant challenge. Standardizing practices and ensuring compliance across diverse stakeholders in varying economic contexts remains an ongoing struggle.

Technological and infrastructural gaps present formidable challenges to the widespread adoption of circular practices. While the CFE relies on advanced technologies for efficient recycling and waste management, many regions lack the necessary infrastructure. Bridging these technological gaps is crucial for the scalable success of circular initiatives.

The economic viability of circular fashion initiatives is a critical consideration. High initial investments in recycling technologies and sustainable materials may not yield immediate returns. Convincing businesses to prioritize long-term sustainability over short-term profits remains a persistent challenge, particularly in an industry often driven by rapid turnover.

Changing consumer behavior and preferences poses another hurdle. Despite growing awareness, deeply ingrained buying habits and preferences for new, trendy items present challenges. Encouraging consumers to embrace a slower fashion cycle, prioritize durability, and engage in circular practices such as clothing rental requires a significant cultural shift.

Moreover, navigating diverse and evolving regulatory frameworks adds complexity to the Circular Fashion Economy. While regulations can steer the industry towards sustainability, a complex web of standards and compliance requirements presents challenges for businesses. Achieving a harmonized, globally accepted regulatory framework is an ongoing process.

Lastly, there is a concern about the potential for greenwashing within the industry. The popularity of sustainability has led to the adoption of circular fashion terminology without substantive changes in practices. This dilution of the term can undermine the genuine efforts of businesses committed to sustainability and erode consumer trust.

5. Discussions

The pursuit of sustainability in the fast fashion industry is at the forefront of global conversations, driven by an urgent need to reconcile fashion's impact on the environment. In this discussion, we critically explore the transformative potential and challenges associated with sustainable innovation in fast fashion, focusing on materials, packaging, processes, and the Circular Fashion Economy.

Sustainable Materials: Bridging the Gap Between Promise and Reality

While the adoption of regenerative cellulose filaments and compostable packaging signals a positive step, the industry must confront the challenge of scale and accessibility. The shift towards sustainable materials remains contingent on overcoming barriers related to cost, production scalability, and consumer acceptance. The real impact of these materials will hinge on their widespread adoption and integration into the broader fashion landscape.

Moreover, a critical examination of the innovative dyeing protocol that claimed a 50% reduction in production costs and a 55% decrease in CO_2 emissions raises questions about the scalability and reproducibility of such results across diverse contexts. Transparency and standardized methodologies for assessing environmental gains are crucial to ensuring the credibility of such claims.

Packaging Innovation: Balancing Aesthetics and Environmental Impact

Compostable packaging is undoubtedly a positive stride toward reducing the environmental burden of fast fashion. However, the industry must grapple with the tension between maintaining visually appealing packaging – often a cornerstone of brand identity – and the imperative to embrace sustainable alternatives. The challenge lies in persuading consumers to value eco-friendly packaging over traditional aesthetic choices, a task that requires strategic communication and a cultural shift in consumer behavior.

Additionally, the broader implications of packaging innovations need closer scrutiny. The potential unintended consequences, such as the energy-intensive production of certain compostable materials, must be acknowledged. Striking a balance between reducing waste and considering the holistic environmental impact of alternative materials is a delicate equilibrium that the industry must navigate.

Processes: Unveiling the Challenges of Transformation

The integration of ecodesign, life cycle assessment, cleaner production, and other sustainable processes into the fast fashion industry faces multifaceted challenges. Despite the potential benefits, the widespread implementation of these strategies is impeded by entrenched practices, economic considerations, and the complexities of global supply chains.

Ecodesign, while holding promise, necessitates a fundamental shift in design culture. Embedding sustainability in design education is proposed as a catalyst for change, yet the practicalities of reshaping entrenched design philosophies remain a formidable hurdle. The industry must grapple with the inertia of existing norms and foster an environment that incentivizes and rewards sustainable design practices.

Life cycle assessment, despite being a valuable tool, requires standardized methodologies and industry-wide consensus on metrics to ensure the credibility of assessments. The lack of uniformity in assessment approaches raises questions about the comparability and reliability of different studies.

Cleaner production and eco-efficiency initiatives, while showcasing technological advancements, often encounter resistance due to their upfront costs and perceived impacts on profit margins. The challenge is to demonstrate the long-term financial benefits of these innovations, aligning economic goals with environmental stewardship.

Waste handling, despite innovative strategies, faces challenges in incentivizing collaboration among stakeholders, from raw material providers to end consumers. Effective waste management requires a comprehensive, systemic approach that transcends individual company initiatives.

The enzymatic textile process introduces a novel avenue, yet its socio-economic and regulatory challenges underscore the complexities of transforming entrenched industry practices. Integrating enzymatic processes into mainstream production requires overcoming economic and logistical barriers and demands a broader systemic shift in industry dynamics.

Circular Fashion Economy: A Paradigm Shift with Structural Hurdles

The transition to a Circular Fashion Economy holds promise as a comprehensive solution. However, the industry must grapple with the critical challenge of upending traditional linear models. Legislative measures set to take effect by 2025 present both opportunities and hurdles. While regulations can act as catalysts for change, the fast fashion industry must navigate the fine line between compliance and genuine commitment to circular practices.

The role of designers in this transition is paramount. While there is a call for sustainability to be embedded in design education curricula, the effectiveness of such initiatives hinges on overcoming ingrained cultural norms and industry pressures. The fast fashion ecosystem must evolve to incentivize and reward sustainable design practices, fostering an environment where innovation aligns with profitability.

6. Conclusions

In conclusion, the exploration of sustainable innovation in the fast fashion industry, encompassing materials, packaging, processes, and the Circular Fashion Economy, reflects a dynamic and evolving landscape. As the industry grapples with the imperative to reconcile fashion's intrinsic environmental impact, the pursuit of sustainable practices has emerged as both a beacon of hope and a complex challenge.

The transformative potential of sustainable materials, from regenerative cellulose filaments to compostable packaging, signifies a paradigm shift towards reducing the industry's reliance on unsustainable resources. However, the realization of these innovations hinges on overcoming barriers related to cost, scalability, and consumer acceptance.

Packaging innovation, particularly in the form of compostable materials, underscores a positive stride towards minimizing the environmental footprint of the fast fashion industry. Yet, the tension between aesthetic preferences and sustainable alternatives poses a significant challenge. Convincing consumers to prioritize eco-friendly packaging over traditional visual appeal requires a strategic cultural shift.

The integration of sustainable processes, including ecodesign, life cycle assessment, cleaner production, and waste handling, highlights the industry's commitment to holistic environmental stewardship. However, challenges abound in reshaping entrenched design cultures, navigating diverse regulatory landscapes, and ensuring economic viability amid the upfront costs of transformative technologies.

The Circular Fashion Economy emerges as a comprehensive vision for a closed-loop system, promising resource conservation and reduced environmental impact. Yet, the complex supply chains, technological gaps, economic considerations, and the need for a cultural shift in consumer behavior pose formidable challenges. Navigating these complexities requires not only industry-wide collaboration but also a nuanced understanding of the interplay between economic, environmental, and societal factors.

As the fast fashion industry steers towards circularity, designers, businesses, and policymakers must grapple with a delicate balance. The promises of sustainability need to be weighed against the economic realities of the industry, the intricacies of global supply chains, and the necessity for widespread consumer adoption of eco-friendly practices.

In essence, the journey towards sustainable innovation in fast fashion is ongoing, marked by both encouraging strides and persistent challenges. A critical examination of these aspects is vital for steering the industry towards a more responsible, resilient, and sustainable future. The synergy between technological advancements, regulatory frameworks, consumer behaviors, and industry practices will ultimately shape the trajectory of the fast fashion landscape, influencing its contribution to a more sustainable global ecosystem.

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