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SUSTAINABLE FASHION AND CIRCULAR ECONOMY FOR EFFECTIVE WASTE MANAGEMENT IN THE FASHION INDUSTRY: A NARRATIVE REVIEW

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ABSTRACT

This paper reviews the digital transformation of the fashion industry, focusing on the alignment with sustainability principles through the integration of sustainable clothing technologies. The introduction emphasizes how urgent it is to switch from linear production techniques to circularity and digitally enabled systems that promote resource efficiency and a circular economy. The primary research questions focus on how circular and sustainable production contributes to efficient waste management solutions, how waste management is oriented in the fashion industry, and how sustainable clothing technologies have a major influence on waste management objectives. The theoretical framework examines the fashion and textile industry's sustainability and highlights the necessity of a green transformation made possible by digital technology to lessen its effects on the environment. The paper also examines how the fashion and clothing business has developed into a high-tech sector, emphasizing innovations like digital printing, CAD-CAM systems, and 3D technologies that increase accuracy, cut waste, and promote sustainable practices. The review concludes by highlighting the critical roles that interdisciplinary cooperation, legal frameworks, and skill-development investments play in overcoming the difficulties associated with putting digital and sustainable practices into practice in apparel sector. It makes the argument that developing a robust and sustainable fashion and textile sector that is in line with social and environmental objectives requires a calculated embrace of digital ecosystems and apparel technologies.

Keywords: Sustainable Fashion; Circular Economy; Waste Management; Environmental Sustainability.

1. Introduction

1.1. Overview of fashion industry and Environmental sustainability

The fashion industry, an important global economic sector, generates a lot of trash and uses a lot of resources, which causes environmental problems. It also plays a major role in the global economy and has a big impact on environmental sustainability and economic growth. The industry's expanding size exacerbates resource waste and environmental pollution problems as consumption levels climb.[1]. Circular economy business models are based on the establishment of closed production systems where resources are kept in use for a longer period [2]. Environmental sustainability refers to a marketing strategy that uses methods that do not negatively impact the environment or natural resources during their life cycle such as, producing, consuming, storing, and disposing of them[3]. Environmental sustainability, from an entrepreneurial standpoint, is also a marketing plan for using processes that do not have negative effects on the life cycle of natural resources (gathering, production, consumption,

durability, energy production, and disposal), the environment or natural resources are considered. Why sustainable fashion is important for waste reduction and the circular economy is the research problem. Textile, apparel, and fashion industries contribute significantly to global environmental pollution at every point of the supply chain. Clothing manufacturing and transportation produce a large volume of waste and high greenhouse gas emissions, often taking advantage of cheap labor in developing countries. This review shows how the concept of sustainable fashion link with the concept of circular economy and the environmental problems that the fashion industry has generated and have been addressed in this review.

1.2. Sustainability in Fashion Industry

There are various approaches to define and operationalize the idea of "sustainability." It has proven difficult to define sustainability precisely in the fashion sector. Furthermore, sustainability is connected to the ideas of corporate social responsibility and transparency, and it can encompass environmental factors like water pollution and greenhouse gas emissions as well as social issues like working conditions[4]. A significant change in how we design, manufacture, and discard goods is reflected in the Essence of the Circular Economy in Fashion, which challenges conventional linear economic paradigms.[5]. The term "sustainability" is broad and helpful in describing the circular economy[6]. It is one of the key issues facing the fashion industry today[7] and the fashion industry is currently at the center of the storm. The fashion industry was obligated to adopt a series of changes toward more sustainable business models [8]. Sustainable fashion is an endeavour that draws together sustainable development and fashion[9]. Sustainability is a concept that addresses the balancing act of human society and the planet’s well-being[10]. Sustainable fashion design embraces a number of dimensions of the circular economy, from the initial selection of materials to the longevity of garments and their potential re-use[11]. The existing linear fashion system makes things more difficult by requiring faster changes in styles and trends, lowering prices, and producing more collections per year. As a result, the linear fashion system has led to an increase in the unsustainable and uneconomic use of energy and non-renewable materials[12] [13]. In recent years, sustainability has become a megatrend, and the emergence of sustainable fashion may be attributed to the global fashion industry's transition to a more responsible structure[14].

To enhance waste management and facilitate the transition to a CE, circular design needs to rethink and reinvent goods and services. In addition to techniques to promote circularity at the end of products' useful lives, such as repairing, reusing, recycling, and remanufacturing, the design of circular systems should incorporate methods to increase the lifespan of items, such as swapping, renting, leasing, and repairing [12]. Three key principles are employed in the fashion industry to achieve a Circular economy: first, the industry aims to reduce waste and pollution through design; second, it can adopt a Circular economy by reusing materials and products for longer periods; and third, it can adopt a Circular economy by regenerating natural systems. The fashion industry can also embrace the Circular economy by using renewable energy or biodegradable resources in fashion production, which can be recycled and reused within aerial cycle[15].

The circular economy's tenets serve as the foundation for methods of reducing, closing, and delaying resource flows; putting these tactics into practice can help create sustainable systems. In addition to reducing, reusing, recycling, and recovering resources from production and consumption processes, the objective is to disentangle resource use from economic expansion. At the product level, the development stages determine up to 75% of the production costs and up to 80% of the environmental effects of the product. Thus, through addressing resource utilization, circular product development has the potential to create economic and environmental value. [16].

The environmental aspects of sustainability using five criteria: sustainable fibers and materials, sustainable fashion design methods and approaches, the impact of clothing technologies on sustainability, the sustainability issues arising from textile product washing, and waste utilization[17].

Fig. 1 Sustainability fiber and materials [18]

1.3.Clothing technologies for sustainable fashion industry

In the immersive technology portfolio, the clothing technologies include 3D simulation and visualization, Computer-Aided Design (CAD), and then 3D printing and additive manufacturing. This is because these technologies allow users to manipulate virtual environments, creating a somewhat more "immersed" experience than 2D renderings. These 3D and virtual technologies may be regarded as belonging on the virtuality continuum, even if VR is frequently characterized by complete immersion and synthesis. However, because it takes a long time and requires a lot of technical know-how to adapt the 3D models for VR/AR, the usage of VR/AR in CAD is sometimes restricted to viewing the models rather than manipulating them [4].

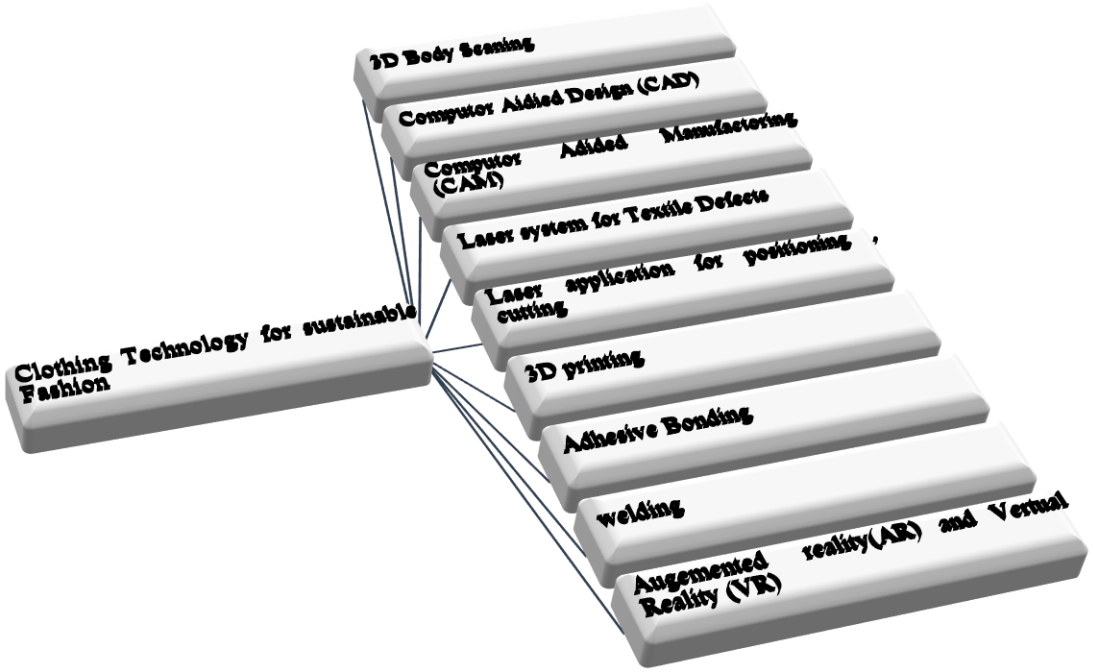

Fig. 2 Clothing technologies for sustainable fashion [18], [19]

The above figure a range of advanced technologies that are transforming the fashion industry toward more sustainable practices. It includes tools such as 3D body scanning, CAD (Computer Aided Design), and CAM (Computer Aided manufacturing), which contribute to reducing fabric waste, improving design accuracy, and enabling mass customization. Technologies like laser systems for textile defect detection and precision cutting enhance quality control and materials efficiency, while 3D printing supports zero waste and on demand production. [19]These innovations minimize resource use and optimize processes throughout the garment lifecycle. Augmented Reality (AR) and virtual Reality (VR) technologies enable digital try-ons and virtual fashion shows, reducing overproduction and the need of physical samples. Collectively, these clothing technologies offer solutions that align with the principles of environmental sustainability, circular economy, and smart manufacturing, helping the fashion industry reduce its ecological footprint and move responsible future.

1.4. Effect of Apparel Waste in the Environment

The overconsumption of fashion generates millions of tons of textile waste annually and necessitates a transition model for sustainability and a circular economy. It also results in an excessive use of energy and natural resources, primarily fibers and water[20]. The fashion industry is estimated to account for 8–10% of global carbon emissions, 20% of wastewater, and more energy consumption than aviation and shipping combined[4]. The second most polluting sector of the global economy is the fashion industry. It must be changed to a more sustainable one for this primary reason[17]. Fashion industries have a huge environmental impact, with increasing consequences all around the world[21][22]. Eight to ten percent of global greenhouse gas emissions, which are known to be the primary cause of global warming, come from

the textile, clothing, and fashion industries[23]. The textile industry faces significant challenges related to the generation and management of waste throughout its manufacturing processes. These problems have far-reaching implications for both industry and try and the environment[24]. Reducing waste in the clothes manufacturing process has to be one of the most important ways to achieve higher sustainability in the context of mass production. Textile waste is a byproduct of garment cutting, sewing problem identification, and quality inspection of textile materials in clothing manufacturing enterprises[18]. The worldwide textile sector, which includes the fashion, garment, and footwear industries. The textile industry's main environmental impacts include the release of significant chemical loads as a result of the industry's high-water consumption and use of hazardous chemicals. water pollution, energy consumption in manufacturing operations, air emissions, problems with packaging and waste management, and the creation of harmful vapors from bleaching, dyeing, and printing processes. Some of the biggest detrimental consequences on the economy and ecology in the world are caused by the textile industry[3].

2. Theoretical Framework

2.1. Key theories/models in sustainable fashion

circular economy originates from ecology and systems engineering, emphasizing sustainable development through efficient resource utilization and recycling[25]. A circular economy is an economic model; The primal aim of this model designed to minimize waste and make the most of resources[26]. In a circular economy, the goal is to keep resources in use for as long as possible, extracting the maximum value from them while in use, and then recovering and regenerating products and materials at the end of their service life. Circular economy model emphasizes three key principles: Design for Longevity and Reusability, Resource Efficiency, and Regeneration and Closed-Loop Systems. [27]

a. Circular fashion Model Linear fashion economy Model b.

Fig. 3 Circular vs. Linear fashion economy Model [27]

Circular economy model is also the other approach involves sharing, reusing, and recycling already existing materials and goods. This idea has been used to help revitalize industrial areas that are in a state of decline. In order to expand and survive in the face of intense global rivalry and resource consumption, the European fashion industry works to adopt cutting-edge tactics like the Circular Economy Model. A circular economy has replaced the conventional linear model of the extraction, manufacture, and consumption of raw resources as the dominant economic paradigm (see Figure 3 a). By reusing, repairing, and recycling, Circular economy model seeks to

maximize a product's life cycle from origin to production and consumption to disposal while reducing the environmental effect of production and consumption. Approximately 20% of all textiles are recycled globally, and the fashion sector primarily uses the conventional linear approach [28].

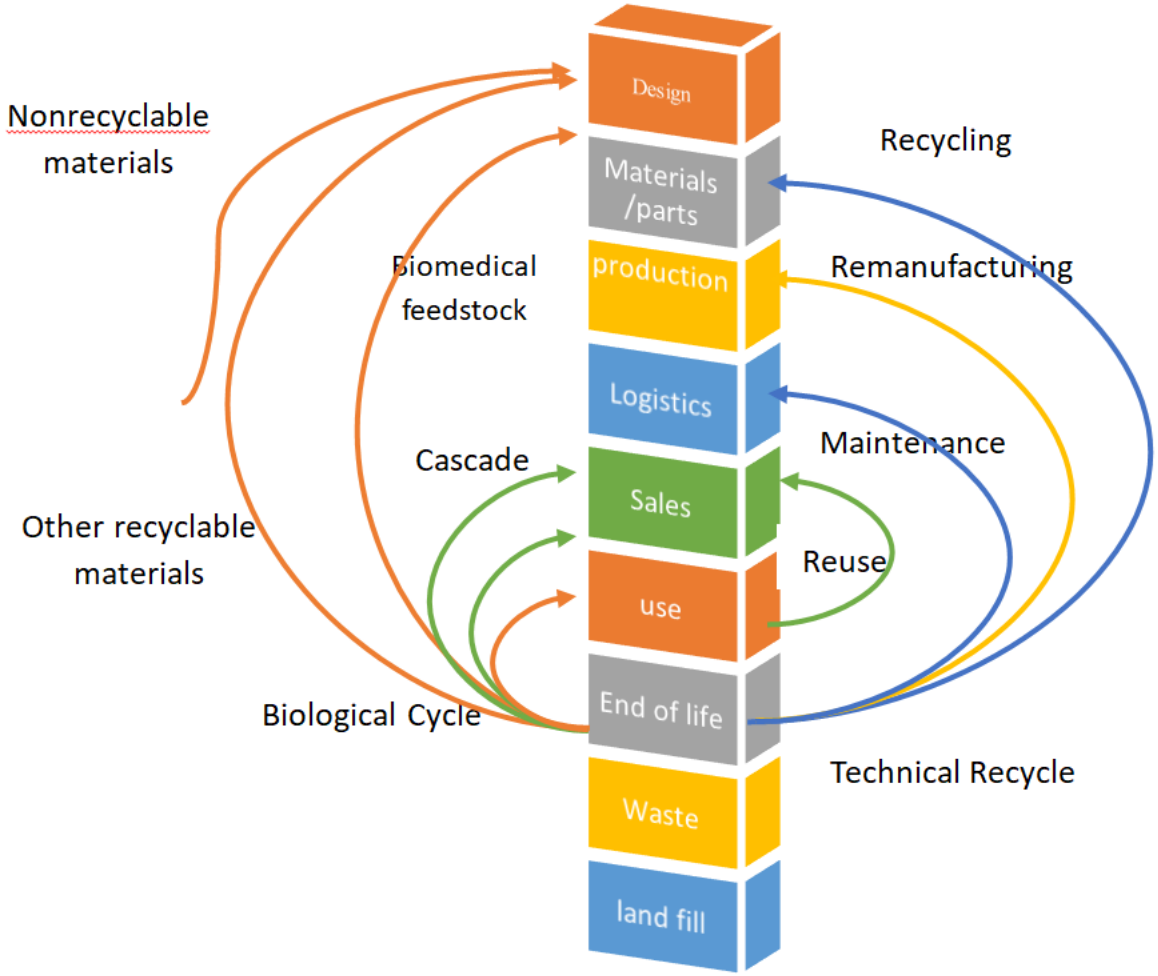

Fig. 4 Concept of circular economy principle [25]

The circular economy's models incorporate recycling, reuse, and resource conservation. Through green design, low-pollution, high-efficiency production methods, and lower energy and raw material consumption, the Resource Conservation Model optimizes production processes and increases resource usage efficiency, thereby minimizing waste creation and resource consumption. By encouraging second-hand sales, rental services, repair and upgrade services, expanding product service life and enabling multiple uses, and creating reusable and readily disassembled items, the Resource Reuse Model lowers the demand for new resources. Re-entering the production process through waste recycling and regeneration, creating comprehensive waste recycling systems to create a closed-loop resource flow system, creating circular economy industrial chains through enterprise collaboration, and promoting technologies that increase recycling rates and regeneration quality are the main objectives of the Resource Recycling Model[25].

Sustainable fashion is increasingly defined by innovative business models that prioritize environmental and social responsibility. Key models include circular economy principles, slow fashion, and clothing leasing, which collectively aim to reduce waste and promote ethical practices.

These models are reshaping the fashion industry by integrating sustainability into their core operations.

The first model is the Circular Economy: It focuses on resource recycling and minimizing waste through product design and lifecycle management. For Example, Brands like Patagonia utilize circular business models (CBMs) to enhance sustainability and economic viability[29].

The second model, Slow Fashion, emphasizes quality over quantity, encouraging consumers to buy less but better. The impact of this model reduces overproduction and promotes ethical labor practices, contrasting sharply with fast fashion's mass production model[30], [31]. *The third model,* Clothing Leasing: This model offers consumers the option to lease garments instead of purchasing, reducing waste and promoting reuse. This model supports sustainability by ensuring ethical labor conditions and utilizing eco-friendly materials[32].

3. Waste Management in the Fashion Industry

The second-largest polluter in the world is the fashion industry, which also contributes to the textile waste issue caused by yarn, fabric residue, and fibers that are mostly made in factories. Just 20% of the world's garment waste is gathered for recycling or reuse. As a result, the European Parliament has developed a circular economy policy to encourage a sustainable lifestyle of reuse and repair [28].

Fig. 5 The environmental impact of fast fashion [33]

From 100 billion garments produced each year, 92 million tons end up in landfills[34]. Explain how fast fashion has a big impact on the environment using the above figure. The fashion business accounts for almost 10% of worldwide carbon emissions and is the second-largest water consumer, according to the UN Environment Programme. The effects of fast fashion extend beyond the environment. In actuality, the sector also causes social issues, particularly in emerging nations. Therefore, slow fashion is the popular response to fast fashion and its effects on the environment, as well as the case for reducing wasteful production, convoluted supply networks, and unthinking consumerism [33].

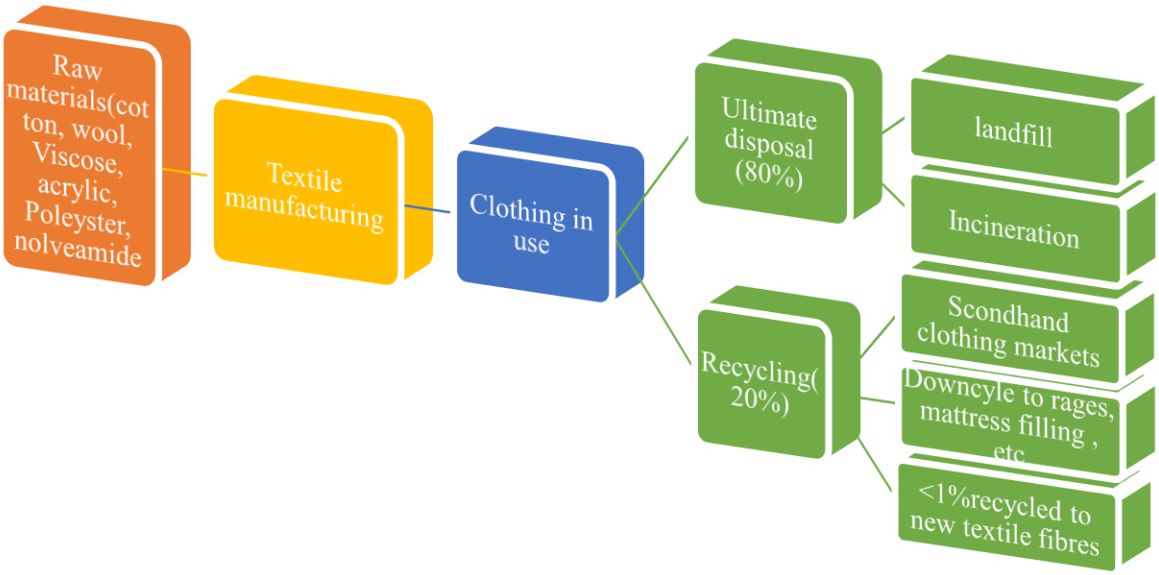

Fig. 6 Textile waste flow from raw material to disposal [35]

The figure illustrates the lifecycle of clothing from raw materials to end-of-life outcomes, emphasizing the imbalance between disposal and recycling. It begins with the use of various raw materials such as cotton, wool, viscose, acrylic, polyester, and polyamide, which are processed through textile manufacturing to produce clothing. After use, 80% of clothing ends up in ultimate disposal either in landfills or through incineration causing significant environmental impact. Only 20% of used clothing is recycled, primarily through secondhand clothing markets or downcycling into low-value products like rags and mattress filling. Alarmingly, less than 1% of clothing is recycled into new textile fibers, highlighting a critical gap in circularity and the need for innovation in textile recycling technologies. The low rate of recycling into new textile fiber underscores the need for systematic change to achieve a circular economy in fashion [35].

The circular model's primary goal is to reduce waste. To accomplish the aforementioned objective, the following strategies should be used: recycling, reusing parts, reselling clothing, processing to give it new functionality, and long-term use of high-quality products. In addition to addressing the toxicity of waste due to its seepage into soil and groundwater, these techniques address the shortage of landfill and incineration sites and offer an incentive to curtail overproduction and consumption, thereby reducing the carbon and water footprint. Textile waste has an adverse impact on the environment and is produced by both textile manufacturers and consumers. [26].

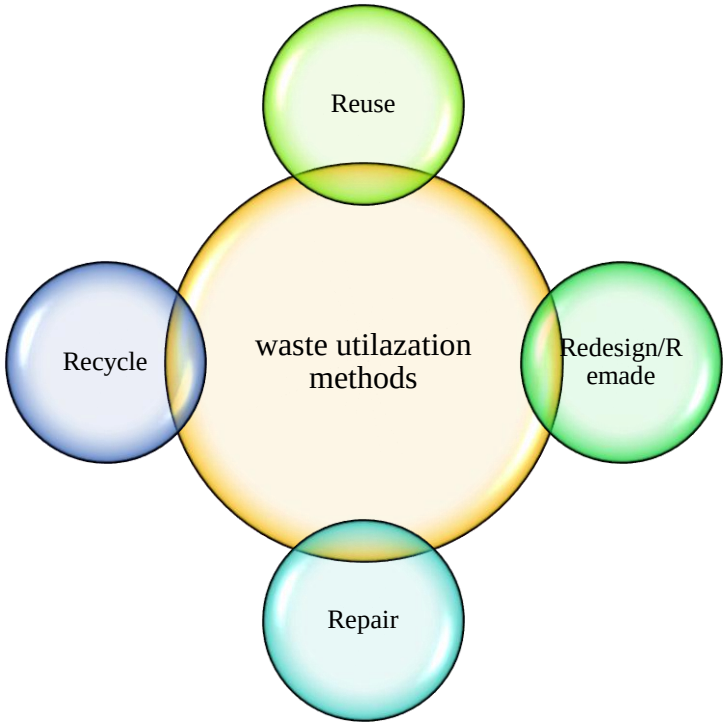

Fig. 7 waste utilization methods [18]

As described in the above figure, waste management is clearly manageable through recycling, reuse, repair, and redesign.

4. Sustainability Strategies for Waste management in the Fashion Industry

The amount of clothes consumed worldwide has increased over the past 20 years from 7 to 13 kg per person, totaling 100 million tonnes, of which two-thirds are disposed of in landfills [36].

4.1. Design for longevity and durability

The design for the sustainable consumption concept is good approach universally used to justify the sustainable fashion industry. Designing for sustainable consumption requires eco-modernist approaches, which seek to modify our present model of production and work against consumerism[8]. Customers base their purchases on certain attributes (a product's inherent and extrinsic traits). In the context of product lifetime, quality (excellent fit, long-lasting materials, superior manufacture, durability in use and laundering), usability (suitability in use, ease of maintenance), and aesthetics (beauty, classic design, color, fit) are all significant factors. Create clothing that is enduring, repairable, and ageless [37] People believe that clothing will increase demand for durable, high-quality goods and that consumers will be prepared to pay more for them [38].

4.2. Recycling and Reuse

Upcycling and recycling are two business strategies that help prolong the useful life of clothing and slow down the fast obsolescence of traditional fashion. Reuse and recycling become essential elements of the fashion industry's Circular Economy in this scenario. Reuse propels the creation of a vibrant second-hand market, where garments find new owners and extend their usefulness[39]. Recycling in fashion (also known as textile recycling) means recovering existing fabrics, materials, or fibres to create new products. Recycling in fashion can also take different forms, from making new garments using deadstock fabric to offering a take-back scheme to prevent old clothes from ending up in landfills[40][41]. Upcycling is another type of recycling method making use of the materials and components of discarded goods to transform them through fashionable design and skilled craftsmanship into new, high value products and keeping them in productive use for longer.

Upcycling can offer an alternative, turning end-of-life garments into fashionable products with a high retail value and assisting the industry to develop more sustainable production methods [42][43]. So, up-cycling second-hand clothes is gaining popularity in sustainable fashion [38]

Fig. 8 Upcycling process used by Worn Again: [42]

4.3. Clothing Rental and leasing models

Clothing rental[44], [45], [46] is Circular Economy Strategies and it focus extensively on consumer acceptance of circular fashion consumption. many prior studies have focused on rental models that offer primarily high-end, luxury, or special occasion wear. rather than everyday fashion, even though from a sustainability perspective, the rental of everyday clothing would likely have a larger impact. Fashion rental as a business model is contrast to traditional fashion-sales models that are product-centered and follow a take-make-waste logic, B2C fashion rental is instead a use-oriented. This focus on slow fashion & sustainability[45]. Apparel renting continues to increase in popularity and rental apparel models are more sustainable than traditional consumption models. The reasons for this greater sustainability include being able to extend the life of products through use intensification and item repair; designing more durable products that last longer to avoid creating unnecessary waste; the need to create fewer products that satisfy more people, which reduces resource, water, electricity, and material consumption[44].

4.4. Resale and Second-hand markets

Since people in third-world nations are suffering from prolonged economic decline, poverty, and declining purchasing power, second-hand clothes are regarded as valuable alternatives for clothing consumption. So, the fashion business has undergone major change as a result of the second-hand clothes movement, which has grown significantly over the past few decades with an annual growth rate of over 11%. Second-hand clothes consumption has attracted attention for its role in reducing waste, promoting social responsibility and offering economic benefits [47]. Second-hand apparel has had a notable standing in the retail market in the past few years. In recent years, the market for used clothing has expanded quickly in response to customers' growing concerns about sustainability[48]. Second-hand clothes markets have become popular for reclaiming discarded items and extend products lifespan[36] and reseal and second-hand garments market have positive implications for environmental sustainability, particularly fashion circularity[49].

4.5. Digital and on demand manufacturing

Digital and demand manufacturing technologies in fashion industry represents a transformative approach and essential for enhancing production efficiency, lowering energy consumption, and

reducing environmental impact. Digital Transformation of the Textile and Fashion Sector technological tools such as automation, artificial intelligence (AI), the Internet of Things (IoT), and 3D printing are revolutionizing how textiles and fashion are designed, produced, and utilized[50].

Fig. 9 CAD for fashion design, pattern development, and 3D visualization [50]

Using CAD technologies allows designers to experiment with various design alternatives, detect possible issues, and implement corrections promptly, all without the cost of creating physical prototypes. In the apparel industry, early CAD system programs primarily concentrated on pattern digitization, computer-based grading, and marker creation for garment production. Designs created digitally are more precise, reducing errors and misunderstandings during garment construction. This enhances efficiency, saving both time and materials, and contributes to a more sustainable and environmentally conscious production process[50].

Recent technological advances in the fashion sector especially print-on-demand and customizable manufacturing are improving sustainability by tackling environmental and social challenges. Print-on-demand transforms production by making garments only after orders are received, which cuts waste and lowers inventory costs. It uses digital printing to apply designs directly to clothing, enabling affordable customization at any scale. The approach is gaining traction because it delivers personalized items, reduces logistics expenses, and quickly responds to shifting trends advantages that matter in fast fashion. By preventing overproduction and reducing waste, print-on-demand supports sustainable and ethical practices while remaining commercially viable[51]. On-demand manufacturing systems, including laser finishing, enhance operational efficiency by lowering costs and increasing responsiveness to market trends[52].

Digital Manufacturing for Customization: Digital technologies facilitate user involvement in the design process, enabling personalized fashion products and supporting distributed production models[53]. Systems integrating textile printers and cutters optimize order aggregation and panel arrangement, minimizing waste during production [54].

4.6. Consumer Education and behavior change

Participation in sustainable fashion initiatives and consumer education allow people to actively contribute to the change and strengthen collective action. Encouraging Customers to take collective action guarantees that the consumer is included in the cooperation. Knowledgeable customers are essential in promoting brands dedicated to the Circular Economy and demanding sustainable practices, which creates conscious demand that completely changes the fashion sector. Building a circular ecosystem in the fashion industry entails not just altering procedures but also encouraging a collaborative and collectivist culture[5].

The pandemic presents an opportunity for the fashion industry to strengthen its sustainability commitment and accelerate business strategies towards a circular model. Sustainability has become a megatrend, with consumers increasingly demanding responsible business practices. This shift in consumer behavior highlights the need to address fashion sustainability issues as they become significant determinants in purchasing decisions. [14].

5. Conclusions

In the current scenario the fashion industry is approaching to shift toward sustainable fashion production, and using sustainable practice is advisable and essential. Collaborative Efforts across fashion industries have proven effective in advancing sustainable fashion development. Collaboration between fashion Designers, consumers, government, corporations, on-governmental organizations and industries promote the rapid implementation of sustainable practices by establishing a framework for sharing of knowledge and resources.

The fashion industry's increasing waste crisis, which happened by rising global clothing consumption and landfill dependency, demands quick and multidimensional sustainability strategies. All of these approaches design for longevity and durability, recycling and reuse, clothing rental and leasing models, resale and second-hand markets, digital and on demand manufacturing, and consumer education and behavior change work in harmony as an inclusive sustainable waste management in textile and fashion industry.

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