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REVIEW PAPER

Towards Circular Economy in Fashion: Review of Strategies, Barriers and Enablers

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Abstract
Circular economy business models are based on the establishment of closed production systems where resources are kept on using for a longer period. Despite the strong desire and demand of the fashion industry to become circular, less is understood regarding the concepts and application of circular economy in the fashion business. This paper offers a holistic understanding about circular fashion, by synthesizing the literature to derive a comprehensive definition for circular fashion and providing a framework of strategies that facilitate the move from linear to circular fashion. Moreover, the barriers and enablers for the transition are discussed by consolidating different viewpoints. This analysis provides useful insights for the designers, researchers, businesses and innovators to support the transition towards circular economy in fashion.

Keywords Circular economy · Circular fashion · Circular textiles · Sustainability · Fashion industry

Introduction

Fashion industry consumes substantial amounts of resources, creates negative environmental impacts and generates massive quantities of wastes. Rapid development and expansion of fashion industry, fast-changing fashion trends, global-scale mass manufacturing model, extension of production to developing countries and the landfill of waste have significantly contributed to increase the environmental issues [1, 2]. Global material consumption was 79 Gt in 2011 and predicted to be increased up to 167 Gt in 2060 [3]; textile is the fourth highest impact category in terms of material consumption in EU after food, housing and transport [4].

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Textile is also ranked as the second highest for land use, fourth highest for water use and the fifth highest for greenhouse gas emissions [4]. Total greenhouse gas emission of the textile industry was 1.2 billion tons of CO_2 equivalent in 2015 [5]. Textile industry also consumes 98 million tons of non-renewable resources every year and the input of fossil fuel feedstock is estimated to be reached 160 million tons by 2050 [6]. Textile production, dyeing and finishing treatments use more than 8000 chemicals [7].

Clothing prices have fallen more than 30% between 1996 and 2018, which means more clothing are bought and consumed at much less prices. Clothing production has been doubled in between year 2000 and 2015, and exceeded 100 billion in 2014 for the first time, which was equivalent to 14 items of clothing for every person on the earth [5, 6]. These resource-intensive production and consumption are mainly driven by the growth of middle-class population and the fast fashion phenomenon, resulting in the extraction and consumption of more and more resources to fulfil the demand. Average number of times a garment is worn before it is disposed has decreased by 36% than 15 years ago, which means frequent disposal of useful clothing (before reaching end-of-life) has been increased [6]. However, less than 1% of used clothing are recycled into new clothing, which represents a loss of around USD100 billion worth of raw materials every year [6].

The concept of circular economy gained an increasing attention in recent years as a way of overcoming sustainability issues embedded in the linear system, such as material scarcity, climate change, depletion of natural resources and waste generation [8–10]. To decouple economic growth from resource use, the importance of shifting towards regenerative growth models that reduce the consumptions and increase circular material use has been emphasized [6, 11]. The fundamental to a circular economy is that the resource flows are optimized, and resources are circulated in a closed loop over and over again, thereby reducing the virgin material and resources requirements [12–16]. Three key strategies to achieve circular economy are defined as slowing (slow down the resource use), narrowing (use fewer resources) and closing the resource loops (close the loop between post-use and production) [12]. Circular business models hold the promise to provide significant environmental, social and economic benefits, and can be implemented in a wide range of business settings and can be individually tailored based on one or several resource loops [9]. Many countries and regions in the world are attempting to redesign their economies by adopting the concept of circular economy [17–19]. European commission published a new circular economy action plan in 2020, aiming at more cleaner and competitive Europe, and textile (clothing and fabrics) has been identified as a priority product based on its environmental impact and circularity potential [11]. Canada has taken a number of initiatives to promote circular economy by introducing Extended Producer Responsibility Schemes (EPR) and a number of zero-waste programs [18]. China has adopted circular economy as a way to tackle environmental pollution and the scarcity of resources in various industries [20].

Current fashion system works in a linear economy model, which believes the resources are infinite [10], exposing the fashion industry to an environmental risk. This traditional linear system is driven by 'take-make-waste' scenario that drives overconsumption and frequent disposal, thus extremely wasteful. Despite the environmental concerns, many efforts are still being made to accelerate the linear system. To reduce growing environmental pressure from the fashion industry, a systematic shift towards circularity is essential [4]. Circular economy in fashion business is emerging as a priority while many fashion brands are committing to reduce resource use, carbon emissions and waste. However, application of circular economy in fashion business is relatively unexplored and thus little is understood by the industry and

academia [21]. Sustainability principles are often targeted by the fashion industry than circular economy principles, yet the goals of sustainability are open-ended, while circular economy focuses on closed-loop systems [14]. Moreover, circular economy is often misunderstood as an approach to mere waste management [17], which hinders the application of circularity principles in the fashion industry. In order to fulfil this knowledge gap, a holistic understanding of circular fashion and its application is immensely necessary.

While numerous publications that address the sustainability and waste management issues in the textile and fashion industry are available, publications that exclusively provide a holistic understanding of circular fashion phenomenon are rare. Previous studies focusing on circular fashion are mostly limited to a single circular system such as textile-to-textile recycling [2], product take-back initiatives [22], clothes swapping [23], online renting [24], consumer attitudes towards circular fashion [18, 25, 26], sustainable design strategies [27–30] and drivers/challenges [31, 32]. This points out the need to consolidate the existing knowledge to aid a better move from linear to a circular fashion system. This paper aims to fill this gap by contributing to a state-of-the-art, comprehensive review of circular fashion literature. Through an extensive literature review, the paper analyses four key strategies that support circularity of the fashion industry and discusses barriers and enables for a successful implementation. This paper contributes to the existing literature by providing a definition for circular fashion and a framework for its implementation within the fashion industry.

Methodology

This study employed a systematic literature review (SLR) as an appropriate methodology to achieve the research purpose. This is a method of reviewing literature in a systematic, explicit and reproducible manner in identifying and critically appraising relevant research [33]. An online search was conducted to identify the most relevant academic literature published within last 20 years and written in English (January 2000-December 2020). A broad search was conducted through the ScienceDirect, Scopus and Google Scholar. In addition to the peer-reviewed journal papers, published reports were searched online as there were significantly important circular economy reports published in recent years. Relevant keywords were combined for the search within the databases. Different combinations of the keywords were generated using ‘textile’ OR ‘clothing’ OR ‘fashion’, AND ‘circular economy’.

The first search resulted 935 articles. The results of the three data bases were compared and 453 duplications were removed resulting 482 articles. The articles were further screened through inclusion/exclusion criteria based on the research questions formed [34]. In the first round of screening, selection of articles was done by reading the title and abstract to answer following research questions.

a. What is meant by circular fashion?
b. What are the strategies that support circular flow of fashion?
c. What are the barriers and enablers that hinder or promote achieving circular fashion?

Research articles related to general textile and apparel studies without a focus on circular economy were omitted in this first stage. Moreover, articles that do not demonstrate circular fashion strategies, barriers or enables were excluded. This process identified 135 published articles that fulfil the objective of this study.

A full-text reading was carried out in the second stage of the screening process. Articles without a clear description of its relevance to the circular economy or which do not answer the research questions were excluded from the study. This yielded 64 articles in total. The SLR protocol is demonstrated in Fig. 1. The total of 64 articles retrieved through the two-stage screening process were categorized and analysed based on four topics of circular fashion definition, circular fashion strategies, challenges/barriers, and enablers for the implementation of circular fashion.

Circular Fashion: Definition

A comprehensive definition of circular fashion can aid to improve the understanding of the concept and enhance adoptability. However, many authors who previously published work on circular fashion adopted the definitions of circular economy in general. Ellen MacArthur Foundation defined circular economy as 'an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of

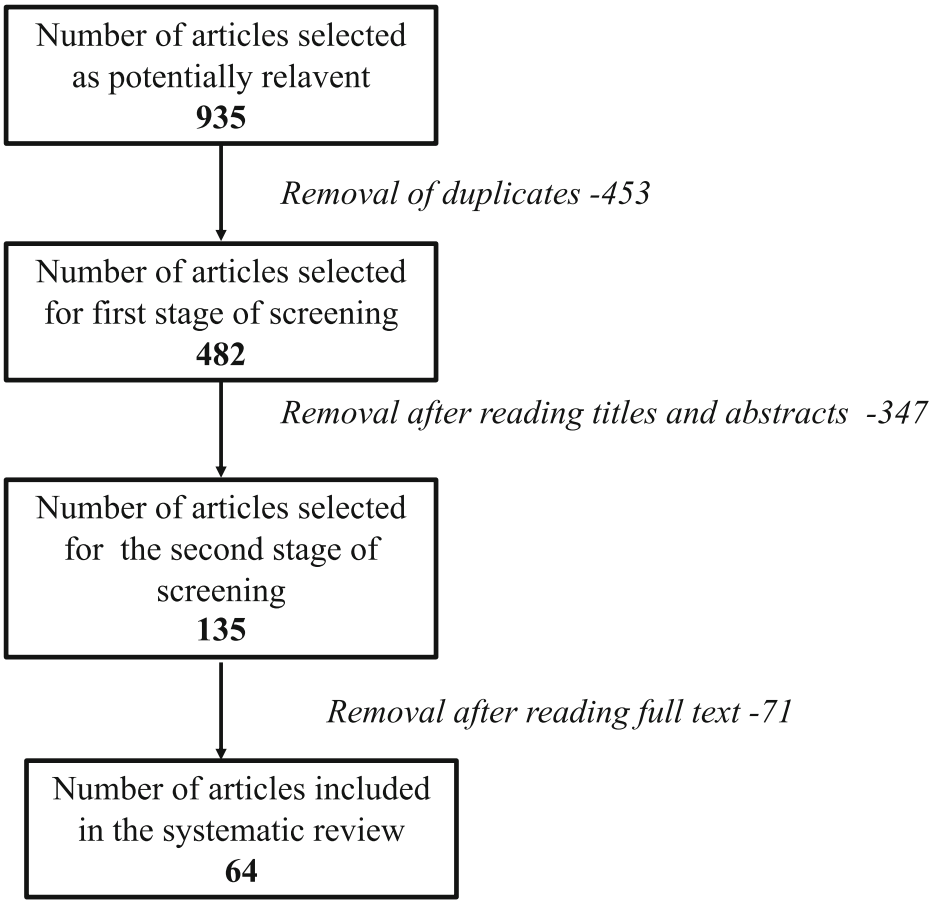

Fig. 1 SLR protocol

renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems...' [13]. Bocken et al. derived the fundamental strategies for resource circulation as reducing, slowing and narrowing resource loops [12]. Kirchherr et al. analysed 114 definitions of circular economy and proposed a new definition as 'an economic system that is based on business models, which replaces the 'end-of-life' concept with reducing, alternatively reusing, and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers, meso level (eco-industrial parks) and macro level (city, region, nation and beyond), which the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations' [15]. Geissdoerfer et al. defined circular economy as a 'regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing and narrowing material and energy loops. This can be achieved through long lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling' [14].

Most of the previous work on circular fashion used the definitions of circular economy, except few. Jacometti described circular fashion as a system that minimizes wastes and keeps materials within the production and consumption loop as soon as possible [35]. Niinimäki emphasized that circular economy in fashion aims to develop closed-loop systems, extend the use-time of garments and maintain the value of the products and materials as long as possible [36]. In summary, circular economy proposes potential solutions to minimize sustainability issues along the fashion product life cycle, which goes beyond the focus of traditional waste management and recycling. It is a system where resource consumption is reduced, production efficiencies are increased, sustainable inputs are sought and materials are repaired, recycled and reused, rather than throwing away. Based on the analysis of different contributions, we define the term circular fashion for this study as *a fashion system that moves towards a regenerative model with an improved use of sustainable and renewable resources, reduction of non-renewable inputs, pollution and waste generation, while facilitating long product life and material circulation via sustainable fashion design strategies and effective reverse logistics processes*, as illustrated in Fig. 2.

Circular Fashion Strategies

Circular fashion can embrace a number of elements of circular economy along the product life cycle from raw material selection to reuse or recycling [1]. The following subsections identify and discuss four key strategies that can aid to make fashion circular.

Resource Efficiency

Resource efficiency focuses on narrowing the resource loops by using fewer resources in making products [12]. It is also aimed at efficient use of resources and reduction of pollution. Material recirculation can lead to save substantial amounts of materials in the production process. To facilitate circularity, it is required to ensure raw material input is safe and healthy to allow circular process and avoid negative impacts along the product life cycle [6]. Resource efficiency of a fashion product can be achieved in three main paths: the use of renewable and sustainable raw materials, reduction of resource consumption and waste minimization, as described below.

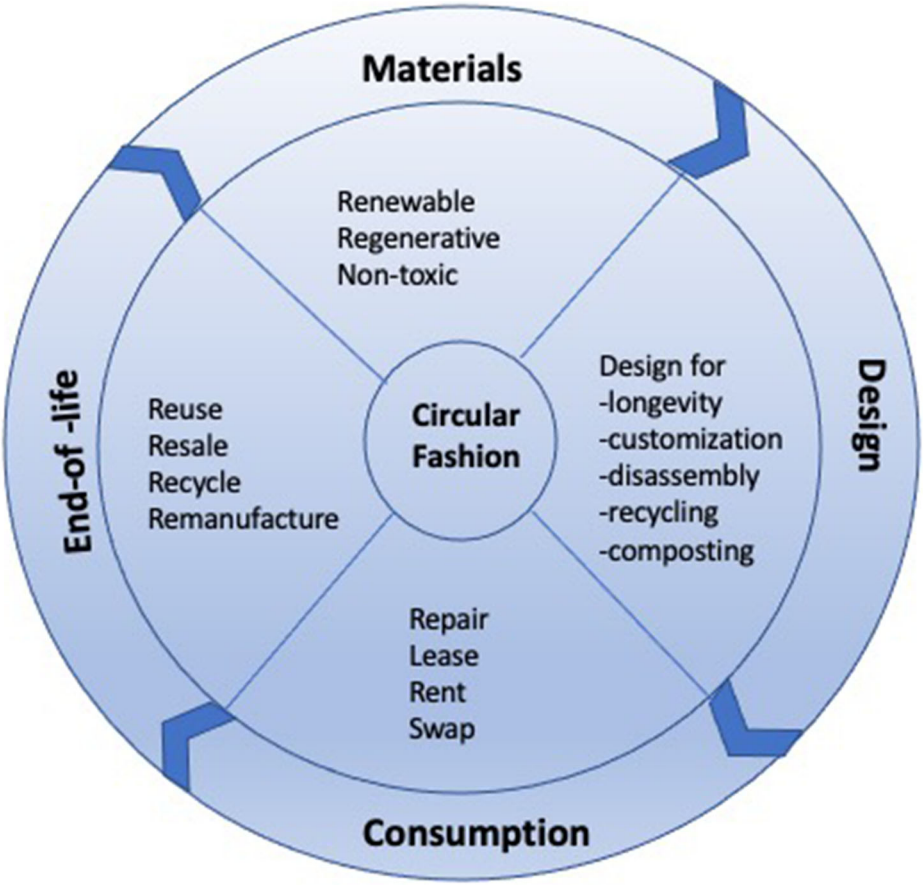

Fig. 2 Circular fashion system

Use of Renewable and Sustainable Raw Materials The selection of raw materials largely determines the environmental impact of a fashion product. Selection of sustainable fibres can substantially contribute to reduce the environmental impact accounted in raw material stage. Strategies that would make fibres more sustainable may vary based on the fibre type. For natural fibres such as cotton, reducing water, land and chemical use during farming should be the priority, whereas for synthetic fibres such as polyester, energy consumption and the use of fossil fuel should be minimized [37]. For instance, organic cotton is considered as sustainable than conventional cotton as organic cotton is grown without using synthetic inputs such as fertilizers, pesticides and genetically modified organisms, thereby supporting biological cycles [38]. Australian-based company Kusaga Athletic developed a range of plant-based sustainable fabrics that could replace traditional fabrics such as cotton and polyester [39].

Current process of textile production involves the use of toxic chemicals as inputs in bleaching, sizing and coloration processes and also in achieving desirable properties. Replacing these toxic inputs with bio-based inputs is essential to reduce environmental impacts. Textiles can be engineered using the concept of biomimicry to obtain desired functionalities without using toxic chemicals. Textiles are already bio-engineered to achieve functional surfaces such as self-cleaning, drag reduction, hydrophobicity and also structural colours [40, 41].

Waste Minimization In a circular economy, products are made to be safely returned to the environment or otherwise designed for reuse or recycle. However, pure biological cycles are not always suitable for some types of clothing which are made from synthetic materials. In such cases, increasing the product life and improving recycling would become suitable circular pathways. Elimination of waste by reusing or recycling leads to cost savings and less resource dependence [13]. Increasing product life is already facilitated by certain brands through repairing and sharing options. For instance, Nudie jeans provides repair kits to the customers to repair their jeans at home [9]. Eileen Fisher, a UK-based brand, offers eco-fashion and encourages customers to return their products to be refashioned and sold again [42]. Rent the Runway (RTR) is a popular designer clothing sharing service in which the membership gets access to rent clothing at a flat monthly price [43].

Not only post-consumer wastes but also pre-consumer wastes made a significant portion of the waste stream, which include cutting and production waste, and unsold stocks in seasonal fashion phenomena. There is approximately 15% of fabric wasted during the cutting process of garment manufacturing. To reduce this cutting waste, designs can be simplified [1], and zero-waste markers can be facilitated by zero-waste design and pattern creation processes. This is a process of designing patterns for clothing without any fabric waste. Zero-waste fashion design has been a niche market, yet circular economy can push this into new design innovation [28]. Moreover, moving to a demand-based production process can provide a sustainable solution in reducing unsold stocks and also production waste. In this case, Zara's fast fashion business model is identified as demand-driven and more accurate sales-led strategy, resulting more efficient production and less waste generation through unsold stocks [42].

Reduction of Resource Consumption Textile industry consumes 93 billion cubic meters of water annually, and beyond production, domestic washing machines require an additional 20 billion cubic meters water per year [6]. Around 20% of industrial water pollution is occurred due to textile dyeing and treatments [7]. Reduction of water consumption can be achieved by adopting latest technologies and modern machineries. 'Air dye technology' is a dyeing technique that uses air instead of water to dye garments, which requires 95% less water and 87% less energy than traditional dyeing [7]. Reduction of water contamination with toxic chemicals, capturing and purifying resultant wastewater from colouration process and reuse are essential to reduce water pollution.

Energy conservation is also paramount in the textile industry as the reduction of energy consumption can bring both environmental and economic benefits. Some strategies are already in place, such as the use of energy-efficient machineries and processes, replacing thermal energy with renewable energy, waste heat recovery and natural cooling systems [44]. Apart from that, less water- and energy-dependent innovations are needed in textile manufacturing process. Resource consumption can also be reduced by replacing virgin raw materials by recycled materials and moving to new fibre types that are produced from agricultural wastes such as banana and pineapple fibres.

Circular design

Design stage is crucial in achieving circularity in fashion. More than 80% the environmental impact of a product is determined at the design stage [45]. In the conventional design process, designers have the power to select materials, trims, silhouette, colours, quality and the design,

and their choices significantly determine the environmental impact of the product [1, 37]. Traditional design teams are pushed for fast fashion cycles and profits and are rarely given opportunities to consider environmental impacts of their designs. Better design and reuse can reduce the cost of raw materials and landfill cost and can create new business models and useful products [13].

Design for circularity focuses on designing the product to be suitable for several life cycles, which is facilitated by the original design [36]. Fundamental to circular design is that products and materials are meant to be repeated in closed loops. Herein, a number of assumptions have to be made regarding the behaviour of actors in more than one life cycle. For instance, consumers are reasonably committed to circular fashion and willing to pass on the garment through several life cycles, and there needs to be a careful consideration of mechanisms that can be used to circulate the product [46]. Products need to be designed for disassembly and reuse [13], and silhouette must be selected to be more adoptable when extending the garment life [1]. Key design strategies that could contribute towards circular fashion are explained below.

Design for Longevity Design for longevity addresses two aspects: design for durability and design for long-lasting. In a circular fashion system, products are designed to be durable so that the product life can be extended and consumption can be reduced [47], which helps slowing the resource loops [12]. Good-quality materials, durable seams and long-lasting dyes that can withstand washing and abrasion are key requirements for product durability [37]. A designer has a vital role to play in designing a product for durability and longevity by incorporating those quality requirements during the product development stage. Clothing can also be designed to adopt changing needs of consumers. Flexible adjustments such as elastics and bands can be included to suit changing body sizes or to minimize fit issues. In the point of sale, offering warranties to repair or replace when the product fails can show a commitment to durability, and increase customer loyalty, while providing a motivation for consumer to bring their products to the store [6]. Moreover, good quality and durability are essential features in selling the garment multiple times (reuse), upcycling or remanufacturing [1, 48].

Design for long-lasting considers the consumer emotional attachment to the product (emotional durability) as opposed to disposable fashion. Designing timeless or trans-seasonal fashion can enhance longevity, because those clothing are free from short-term, seasonal trends. Trans-seasonal products extend the use of item beyond one fashion season and can avoid the items being disposed soon [37]. Moreover, multi-way clothing facilitates the same garment to be worn in few different ways and thus increasing the frequency of using the garment. Interchangeable parts (colours, sleeves) can be provided at the point of purchase which facilitate consumers to try out few different looks. For instance, Swedish outdoor apparel brand Kättermusen designs trousers with functionally, in which detachable pockets and gear-loops are provided [42]. Combining traditional craft into contemporary fashion is also a possible way to increase the attachment to product. Customers are willing to pay higher prices for unique, handmade fashion items and tend to keep them longer.

Design for Customization Customization allow consumer to purchase a garment with a personalized style and fit. In customization process, each customer is personally treated, and the customer becomes a co-designer by actively engaging in the customization process [49], thereby improving customer attachment to the product [50]. Correct fit and personalized features can influence the consumer for a less trend-driven product and a sustainable

consumption behaviour, which may lead to a reduction in consumption and avoid premature obsolesce of clothing. New technology developments can bring customization into the mainstream. Technologies such as 3D body scanning, and virtual prototyping can customize a perfect garment without delay. These digital advancements in the customization process allow customer to analyse the design and fit of the garment before making the purchasing decision, which ensures customer satisfaction as early as the product design stage [50]. Additionally, customization can replace traditional, resource-intensive and polluting industrial printing technology with digital printing techniques such as ink jet and sublimation printing. Those eco-friendly techniques facilitate personalization by offering unique designs in individual garments, while minimizing the use of resources including energy, water and chemicals [51]. Customization can reduce excess production and overconsumption, extend product life and minimize waste generation [50].

Design for Disassembly This is a strategy that ensures component parts can be easily deconstructed for further use. Clothing designs that facilitate easy deconstruction can ensure the reuse, recycling or remanufacturing of all useful component parts. Currently, garments are disassembled manually by unpicking the sewing thread or cutting along the seam [52]. Many useful clothing items are discarded without further processing due to the time and cost involved in the manual disassembly process. Therefore, it is vital to design the product by considering disassembly and end-of-life treatment strategies. Key attributes of the design for disassembly process involves (i) simplification of deconstruction process, (ii) reduction of deconstruction time and cost (iii) allowing recovery of components and materials [53]. That covers many tasks such as appropriate selection of materials, design of components and product architecture and the selection of joints and fastening methods for easy disassembly [54].

Disassembly embedded design should consist of a mechanism of disassembly integrated within the product [55]. Wear2™ Microwave technology already created the possibility of removing threads from a stitch very easily. Wear2 sewing thread can be used to assemble garments which can be exposed to microwave radiation when disassembly needs to take place, thereby dissolving the sewing thread without harming other textile components [56]. This technology facilitates quick and easy disassembly of clothing items for further repossessing. Additionally, design with few component parts and large fabric pieces can make the disassembly and recycling/remanufacturing processes easy. Fewer component parts mean fewer number of seams, which reduces disassembling time, and large fabric pieces allow re-design and remanufacturing them into new garments while minimizing wastages. Moreover, appropriate material selection is important to allow recovery of materials after disassembling. Textile materials are usually blended with different types of fibres which makes recycling difficult. Similarly, mixing different blended materials in the same garment makes end-of-life treatment processes complicated. Design for disassembly needs to ensure the garments are made from mono materials, or else the component parts consist of the same type of material, which can facilitate recycling after disassembling.

Design for Recycling Current linear system does not make a provision for recycling clothes during the design stage. Only 1% of clothing is recycled back into clothing [6] and others are mostly downcycled due to various reasons such as complexities in fibre blends, difficulties in colour removal and lack of technology for recycling. Therefore, aligning clothing designs with recycling options is essential. Proper material selection is absolutely necessary because some

materials make recycling impossible or uneconomical [57]. For instance, fibres are often blended to achieve improved properties of textiles and to reduce production costs, yet this poses technical challenges in fibre separation in recycling [37]. Reducing complexity of materials by minimizing the use of blended materials and increase the use of mono materials would stimulate the rate of recycling [2]. Moreover, avoiding the use of different types of materials in the same product and minimizing surface coating can enhance the recyclability. It has been suggested that the ability of recycling should be a key aspect when introducing new materials and fibres to the textile industry [2]. Candiani Denim, an Italian-based manufacturer, is an example that manufactures denims with the longevity in mind, and facilitates recycling at the end, thus minimizing waste and rapid consumption [21].

Design for Composting When the products are designed to be composed, the best option is to use degradable fibres, which are not altered by applying toxic chemicals during the material manufacturing process and return to the biosphere after using the product. Moving short-lived products such as fashion into purely biological cycles is essential to maintain a healthy environment [13]. Composting may not be a suitable option for all textiles because only few existing fibres can be composted [36]. However, development and the use of bio-inspired polymers in textile manufacturing is one promising approach to achieve compostable fabrics [40]. Clothing made from degradable or compostable plastics would potentially offer a replacement to non-degradable, synthetic plastics. Replacement of toxic chemicals with biomaterials and bio-based coating, and the use of natural dyes in fabric manufacturing process are essential to ensure composability. Furthermore, the accessories and fasteners used for clothing should be made from degradable materials. For instance, a Swiss manufacturer Freitag designed a compostable fabric (F-ABRIC) which is made from hemp, flex and modal fibres. While the clothing made from this fabric are extremely durable, they will break down in a composter in few months after disposal, including the sewing threads and buttons, which are made from nuts [58].

Product Life Extension

Product disposal in a linear system does not recover any residual energy, whereas incineration or recycling capture a small amount of residual energy [13]. Extending product life aims to keep the product in use to the highest extent as possible through design and operational practices [59] It is the best way to minimize virgin material requirement and the energy use in extraction and processing of raw materials. Increasing the number of times that clothing are worn leads to capture material value, reduction of waste, pollution, and the number of items that are purchased [2, 6]. If the average time a clothing is worn were doubled, GHG emissions would be 44% lower [6]. Product-service systems (PSS) such as repairing, leasing and rental models provide a new way of extending product life, focusing on utilization [36], which are explained below.

Repairing Services Repair and maintenance operations can extend the life span of clothing and reduce the use of virgin materials [16]. Repairing services offered by the retailers are emerging, in which customers can bring their clothes to the store and get them repaired. These types of repairing services enable longer product life while creating long-lasting customer relationships and new revenue streams for the retailer [59]. New independent cloth repairing

shops are evolving which offer cloth repairing, mending services and sewing skill workshops, thereby helping consumer to extend the product life. Independent business models such as Clothes Doctor (clothes-doctor.com) provide consumers with a full repairing service package including delivery and returns. Repairing can also be performed by the customer at home; for instance, Nudie jeans sends repair kits to the customers who cannot visit stores in person, but would like to repair their jeans [9]. This type of do-it-yourself (DIY) models is becoming increasingly popular [16]. However, lack of time and sewing skills may discourage consumers to carry out repairing services at home [60].

Sharing Platforms In a circular economy, product should be leased, rented or shared when possible [13], which is also known as collaborative consumption. Rental or leasing can develop collaborative business models to keep clothing in use frequently. Developing durable and fashionable clothing items and making them available via sharing platforms can change the way clothes are bought and consumed. This type of business model can provide environmental benefits and saving of resources when consumers are willing to change their outfits more often, and also when the garment can be worn more times than the owner is willing to [6]. Collaborative consumption facilitates customers to use variety of fashion items in short term and to keep up with latest fashion trends while reducing the resource consumption. Consumers usually dispose clothing due to fit issues or when they no longer like them. Sharing platforms can divert these clothing from being landfilled and keep reutilizing. For rental and leasing models to become successful, quality, durability and trend are the key aspects to be embedded in clothing items. DressYouCan is an Italian fashion rental service that women can rent dresses, shoes and accessories for special occasions at an affordable price. The company created a unique business model for reuse and recycling by allowing clients, emerging designers and brands to share their clothing in this platform with a lower fixed cost [21].

Subscription models that allow consumers to pay a flat fee to rent or lease a certain number of clothing items during a pre-defined time period can be an attractive, cost-effective option for consumers who want frequent changes of their outfits [6, 24]. This business model is becoming attractive among fashion-minded consumers because that allows them to consume latest clothing items including designer brands for around 10% of the actual retail price. It has also become a cost-effective option for consumers in which few clothes can be tried out for the price of one. For instance, Rent the Runway (RTR) is a popular designer clothing rental service in which the member gets access to rent clothing at a flat monthly price. Subscription options allow customers to rent a number of clothing, starting from 4 items, and can extend to rent unlimited items. Forward and backward logistics processes are well organized where reusable garment bags are used for shipping and return services with a pre-paid return label. Drop-off boxes have been introduced to make the return process easy. Rent the Runway attracted customers for their commitments to sustainability that include the reduction of plastic consumption, recycling and toxic-free cleaning process [43]. Haverdash is another rental service that gives women access to fashion rentals through flat monthly fee, which also includes free shipping, return and dry cleaning services [61]. MUD Jeans offers ‘lease a jeans’ option where customers can lease jeans for a monthly fee which includes repair services. Customer can choose to return the jeans after 12 months and swap with a new pair of jeans.

Unlike renting or leasing, swapping allows consumer to exchange clothes without a fee involved. In swapping, unwanted or excess clothes of consumers are handed down to new owners, with the transfer of permanent ownership. Cloth-swap shops are becoming increasingly popular where people meet in person, informally or in formal events, or use online

platforms to exchange clothing. This peer-to-peer clothes swapping facilitates new supply and consumption opportunities; thereby, clothes can be diverted from landfills to alternative supply chains [23]. In order to swap, clothes should be in good condition but may be less than to an ideal. Cloth swapping is beneficial not only in extending life span of clothing, but also when consumers have no money to buy new clothes or when consumers want to find something different than their existing wardrobe [62, 63].

End-of-Life Circularity

From the total fibre input used for clothing production, 87% is either landfilled or incinerated after use, and it is estimated that more than 150 million tons of clothing would end up landfilled or incinerated by 2050 [6]. End-of-life circularity allows to divert clothing from landfills and to capture the value of materials in different forms at different levels by closing the resource loops [12]. At the end of first cycle of use, clothing can be reused, remanufactured or recycled as described below.

Reuse If clothing is made to be durable, they can enter into another cycle of use through secondhand clothing markets. While secondhand clothing markets are well established, there are rising issues with the export of used clothing to developing economies, which undermines local manufacturing in destination countries and increases waste generation. Reusing in a circular economy gives more emphasis on local reuse, and engaging retailers in the circularity process. Retailer owned secondhand clothing lines are emerging, which can reduce the sustainability issues associated with overseas secondhand clothing markets, offers new opportunities for reuse models and creates new customer segments [16] Retailer taking responsibility to take-back, clean, repair and resale of used clothing would increase the customer returns and also reselling possibilities, while developing a trust among users. This type of a process would ultimately increase the usage of secondhand clothing locally [6]. Clothing can also be reused through selling in third-party secondhand stores, handing down to friends and families or sharing through more formal platforms such as cloth swapping.

Remanufacturing Remanufacturing is a useful strategy for extending the life of clothing which are otherwise planned for premature obsolescence. This process involves disassembly of used clothing, recovery of useful component parts, redesigning and resembling them to make new clothing, with a quality level of equal to, if not better than new clothing [52]. Remanufactured clothing may not carry the original identity or functionality; for instance, a trouser can be remanufactured into a coat or a skirt [64]. Remanufacturing is a cost- and resource-effective treatment method than recycling, in which energy or chemical-intensive and polluting treatment processes can be avoided. Being able to easily disassemble a garment is important in the process of remanufacturing. Design process can facilitate easy disassembly by introducing suitable stitch types or bonding methods. Fabrics need to be durable with reasonably good quality, in order to enter them into the remanufacturing process. Some process level challenges hinder scaling up the remanufacturing industry such as sourcing of suitable input, high process throughput time and skill requirements for disassembly and redesigning [65], which may be possible to overcome by designing garments for disassembly and remanufacturing. To enable remanufactured fashion to gain market share, products can be remanufactured as trans-seasonal while targeting sustainable fashion markets. That would

possibly develop a new customer base and avoid the competition with regular seasonal fashion products.

Recycling Fashion industry generates massive amounts of wastes and currently most of the disposed wastes are being landfilled or incinerated. This is mainly due to lack of collection, complexities in separation of various materials and associated cost [66]. Less than 1% of waste is recycled back into clothing, 12% is recycled into low-value products such as wiping, insulation materials and mattress filling, and 73% is landfilled or incinerated [5]. This points out that current recycling industry mostly focuses on downcycling which produces low-value products than the value of the original. However, downcycling does not enable circular approach but only delays the product becoming a waste [12, 67]. Use of recycled fibres to make clothing has been identified as one of the major ways to achieve circular fashion [68]. Improving clothing-to-clothing recycling requires effective product design that facilitates recycling them back into clothing, communication of recyclability via labelling or new technologies such as RFID codes and a traceability along the entire life cycle. Digital receipts can be used to communicate the types of materials and chemicals included in the product, thereby enhancing the transparency for recyclers [2].

Recycling technologies are mainly divided into mechanical and chemical recycling. Mechanical recycling involves melt-extrusion to obtain fibres from waste materials and subsequently re-spun them into yarns. In chemical recycling, materials are depolymerized into monomers and repolymerized back into fibres. Dissolution route is also used in chemical recycling for cellulose fibres such as cotton or viscose, in which ionic liquids are used as solvents to dissolve cellulose [69, 70]. There are a number of initiatives taken by companies to recycle textile wastes. For instance, Worn Again, a UK-based company, developed a chemical recycling technology and partnered with fashion companies such as H&M to recycle textile waste and use them to create circular fashion [71]. Pure Waste and Relooping Fashion are few more examples for creating closed-loop production through textile recycling [42].

Once garments are collected for recycling, effective sorting mechanisms are needed to divert wastes for appropriate recycling programs. Currently, clothing are mostly sorted manually, which has many drawbacks such as the cost, low-speed operation, incapability to classify complex materials and non-standardization [72, 73]. Previous studies reported the possibility of developing automatic sorting techniques such as NIR or FTIR spectra to classify textiles [73, 74], which can improve the circularity of clothing.

Challenges and Barriers

While literature highlighted many challenges and barriers for the transition towards a circular economy, there are differences existing from sector to sector [75]. Textile and fashion industry is not yet fully developed to achieve the overarching aim of circular economy [1]. One of the biggest challenges of creating a circular fashion system is the highly globalized, complex and extremely fragmented supply chain which consists of many stakeholders and activities, making it difficult to ensure circular transparency [10]. As textile and apparel manufacturing firms are largely located outside the Western consumer markets, locating them in the reverse business models is found to be difficult. It is challenging for an individual company to achieve

circularity without an extensive commitment, communication and engagement among all stakeholders in the supply chain [76].

Fashion designers are not empowered to take sustainable decisions during the design process as the decisions are largely influenced by company profit targets. Recycled materials still represent a niche market, thus expensive than virgin counterparts. Some companies are not willing to use recycled materials due to quality concerns [31]. Lack of awareness and education of the workforce regarding sustainability and the environmental impact of their decisions, and the absence of appropriate company polices largely hinder the organization's transition towards circular economy.

Many businesses do not consider waste as resources, but a cost, which hinders the initiatives in closing the resource loop. Recycling of many materials do not occur because recycling is found to be more expensive than purchasing virgin materials [75]. Absence of technologies for material detection and sorting leads to manual sorting operations with extensive labour involvement. These issues indicate lack of economic benefits and market opportunities for recycled textiles [2]. Other key challenges present in textile-to-textile recycling are the diverse mix of materials, colours and finishers present in the fabric. Even if some materials can be recycled either chemically or mechanically, the possibility of scaling up the process, and the economic feasibility are questionable [46]. While chemical recycling is expensive, mechanical recycling does not return a product of same quality [37]. In light of these issues, lack of technology has been considered as one of the key barrier in developing a circular economy [20, 75].

Lack of consumer interest and awareness has been highlighted as one of the core barriers that slow down the transition towards circular economy [75]. Returning used products back to the producer requires consumer commitment and new level of relationship with the producer [13]. Even though textile collection systems are available in developed countries, the collection rates are considerably low, whereas in developing countries, there are no collection programs available. Customers are familiar with the linear business models and convincing them to be a part of circular business models may be challenging, especially when the business is operated in a global scale [9].

One of the major challenges to realize the end-of-life circularity is the absence of effective collection and sorting schemes. Barriers in current sorting technologies such as accuracy in sorting complex materials and the speed need to be eliminated with the development of innovative sorting technologies. Retailers struggle to manage their reverse logistics process due to various reasons such as cost and the requirement of additional workforce and processes. Efficient information system is crucial in decision making and also to plan and manage their resources [20].

Enablers

Circular fashion requires fashion businesses to rethink and rearrange their business models. Moving from linear fashion to circular fashion expects the engagement of all the stakeholders in the supply chain including manufacturers, retailers, suppliers and consumers, and establishing new connections with stakeholders beyond the traditional supply chain [9]. The success of the process will depend on the awareness, knowledge and the commitment of all the stakeholders in the fashion supply chain, together with the key enablers discussed below.

Technology and Innovation Material and technological innovation is a key enabler in transforming linear economy to a circular economy [13]. Innovation of new sustainable materials is essential that could potentially reduce the consumption of cotton and polyester fibres. Innovations are already undertaken to produce cellulose-based fibres from agricultural waste such as banana fibres, pineapple fibres and orange fibres. Moreover, recycled fibres are low impact alternative to virgin fibres, yet economically attractive methods for recycling various fibre types and blended materials are yet to be developed.

Circular business models come with a new set of technology requirements [46]. Innovation in technology to minimize the negative impacts of the production process is required to reduce resource consumption. Cost-effective waterless dye technologies, sustainable printing technologies, zero-waste design and manufacturing techniques are few examples of future innovation potentials in technology. Technological innovation is immensely necessary to enhance materials circulation. Producers should adopt best practices of technological innovations which contribute to reduce environmental footprint [77]. For recycling, there is a need for advanced technology that can identify material content and efficient sorting in large scale.

Efficient Reverse Logistics Processes Current post-consumer clothing collection is highly fragmented with the involvement of many stakeholders such as charities, commercial waste collectors, social enterprises and municipals. Majority of the reuse and recycling businesses are operated by third parties who do not belong to the stakeholder networks of the forward supply chain, and each of them have different interests [52]. Consumers use various routes to dispose clothes and the dominant method of disposing has been identified as donation to charities [78], yet that is a small fraction of total waste. An overall solution for collecting all clothing regardless of the type, quality and quantity is required to provide consumers that may facilitate recycling all types of clothing [79]. Reducing number of informal actors, having a common identity for all collectors, providing incentives for returns and a clear communication on how and where to dispose are the key factors to be embedded in scaling up clothing collections for better reuse and recycling [79].

To reduce the cost and time, keeping the reverse cycle short and less complicated is essential. Organizations need to build up reverse logistics and supply chain capacities by introducing digital technologies for tracking and tracing of resources [11], which can smooth the reverse logistics process. Incentive schemes can be used to promote users to bring back their unwanted clothes. Incentives can be given either by cash upon the take-back or discounts towards the next purchase, which may in turn boost the collection rate [13]. Within a circular fashion economy, products are meant to be circulated several times before discarding. Establishing effective logistics for the circular models such as rental schemes is paramount to maintain customer satisfaction. Efficient delivery as well as return services, followed by quality checking, cleaning and preparing back for renting involve extra workforce and cost.

Awareness and Education The shift towards circular economy must be supported by the educational system. A strong sustainability focus on designer education could be a powerful tool to have a significant impact; thus, traditional design education must be restructured to address the key aspects of circular economy [2, 80]. Moreover, eco-design requires a meaningful interaction between designers, material developers and chemists [2], and therefore, awareness and knowledge on sustainability among all of them is vital in developing a circular product. It is also essential to provide awareness, knowledge, tools and training to all the actors

involved in supply chain to establish long-term success in the circular economy implementation and encourage innovation [81]. Changing consumption patterns towards sharing, longer use, and reuse require a substantial behavioural change of consumers, which has to be facilitated by education and awareness [2]. New concepts such as sharing platforms may need to be backed by heavy marketing, awareness campaigns and retailer commitment to gain consumer interests.

Policy Implementation Circular business models should be supported by appropriate policy implementation. It has been suggested that the key player that may accelerate the transition towards a circular economy is the government [75], and this can be enabled through effective policy implementation. Policy instruments addressing material use, product design, manufacturing, distribution, consumption and waste management are required to support circularity [4]. Governments can enforce regulations for organizations to select their suppliers based on sustainability performances and encourage sustainable manufacturing practices [31]. The EU has announced textiles as one of the priority products in their circular economy action plan, which shows a promising approach to circular textiles through appropriate policies and regulations [11].

Currently, there is no obligation for the consumers to send unwanted clothing for reuse or recycling, and government initiatives in this regard are lacking [79]. Policy measures can support implementing Extended Producer Responsibility principles [36], in which manufacturers and retailers should bear significant responsibility of post-consumer wastes. Providing start-up capital funds for circular business models such as collection, repair and recycling, and offering VAT reduction are some of the ways to encourage new circular business models.

Enhancing Consumer Participation Consumers are showing an increasing interest to move towards circular economy due to their improved awareness on sustainability issues [31]. However, sustainability itself is not yet sufficient to encourage consumer purchasing behaviour as that usually gets a low priority over price [82]. Providing consumers with cost-saving benefits is a way to enhance the consumer participation in the circular economy [11]. Information regarding the easy access to product life expansion options such as repairing, and exchange services should be passed to the consumer at the point of sale.

Product-service business models are an example of keeping customer retention while extending the product life. Nudie jeans offers repair services, provides 20% discount towards a new pair when the old pair is returned, and the returned jeans are washed, repaired and sold as their stores as second-hand clothing, thus encouraging consumers to extend the product life [9].

Consumers do not have a sufficient knowledge about the environmental impact of their clothes, and therefore, educating them is a main requirement in increasing consumer participation for circular fashion activities [83]. The concept of circular fashion is often difficult to communicate to the consumers as that holds a complex meaning than recycling or simply using an organic material for example. Environmental-related information of the product and the recycling potential should be communicated to the consumer. Eco-labelling can be used as a tool for communicating the environmental and social impacts of products [37]. Through eco-label, information such as the sustainability of material and their recyclability, processes used and the social responsibility can be transferred to the consumer.

Discussion

Fashion industry has the potential to develop a diverse range of circular business models. However, the implementation of circularity in fashion is still in its very early stage. End-of-life circularity is found to be predominant at the moment yet prioritizing only waste circulation is often inadequate to achieve the concept of circular fashion. Design for circularity should be the centre of focus because it has been identified that around 80% of the environmental impacts are determined by the design stage [45]. This involves shifting to an entirely new system by using a design thinking approach and bringing the stakeholders together for a collaborative approach [6]. Extending the useful life of clothing, improved and efficient resource flows, the use of sustainable and renewable raw materials and the reduction of waste flows along the entire value chain would be the key features of circular fashion.

The shortage of resources such as water and energy cannot meet the growing demand for fashion apparel produced in the current linear system. Moving from linear to circular fashion may bring major benefits to the fashion industry in terms of water and energy saving, reducing emissions and resources requirements. Such a transition would drive new business models, employment opportunities and a sustainable consumer segment. Circular fashion provides the consumers with sustainable products that are designed for durability and to reuse, remanufacture or recycle in repeat. The need of raw materials and other resources can be substantially reduced if the clothing utilization is increased, lifetime is extended and reutilization via remanufacturing and recycling models. Moreover, clothing rental or leasing options could bring more profit and improved customer relationship to the retailer than a one-off sale of a garment. Hygiene concerns may act as a barrier for rental options in which a procedure for cleaning needs to be established with a guarantee of the cleanliness of the product.

The fundamental to circular design is to rearrange the supply chain. The commitment to circular fashion should be made by the brand owners/retailers as they hold the decision-making power in the entire textile supply chain. Moving towards circular fashion needs a system perspective where all the stakeholders (designers, manufacturers, suppliers, retailers and consumers) are involved, and a shift in mind set is very much essential among all the stakeholders. Every firm that is linked to the supply chain must design firm-specific strategies. Promoting local production and consumption must go hand-in-hand with circular economy not only to enable transparent and efficient reverse flows but also to reduce global-scale resource consumption and pollution. Global, regional and national policies can support this type of a transition.

Conclusion

This review presents a holistic understanding of the circular economy approach in the fashion industry, one of the most polluted industries in the world. This paper makes important contributions to the literature by deriving a definition for circular fashion and compiling a framework for key circular fashion strategies. This study further identified key barriers and enablers for a successful implementation of circular economy practices and highlighted the requirement of moving beyond traditional waste management practices. Application of circular fashion needs a system perspective where all the designers, manufacturers, suppliers, retailers and consumers are involved and committed with a positive shift in mind set. Findings of this review would support to shape the future research agenda on circular fashion.

Availability of Data and Material Not applicable

Code Availability Not applicable

Author contribution Both authors are involved in the research design and the initial review of papers. DGK wrote the first draft. DW revised and edited the draft. Both authors approved the final version of the paper.

Declarations

Conflict of Interest The authors declare no competing interests.

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